

NOVEL METHODS FOR THE PREPARATION  
OF TAXANES USING OXAZOLIDINE INTERMEDIATES

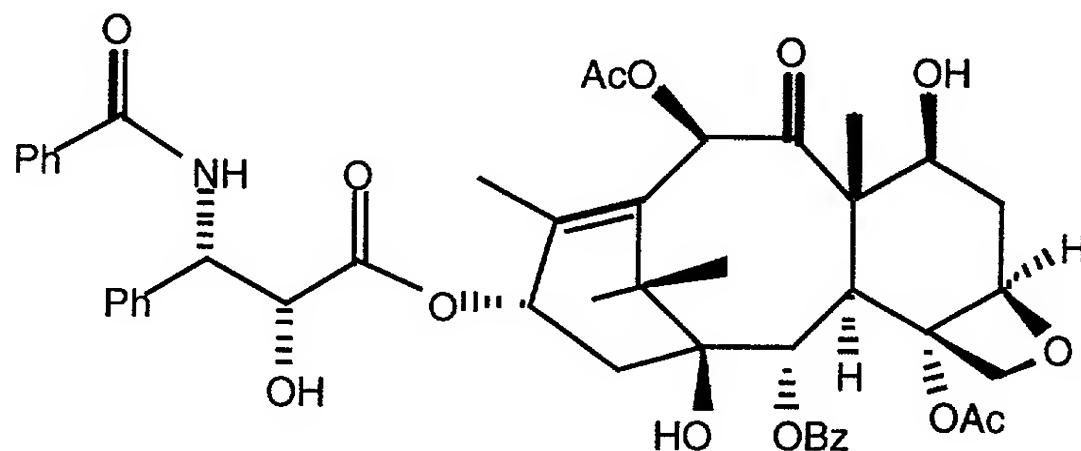
This is a division of 09/315,712, May 20, 1999,  
5 allowed, which is a continuation of 08/845,299, April 25,  
1997, abandoned which is a continuation of 08/408,676, March  
22, 1995, abandoned.

Field of the Invention

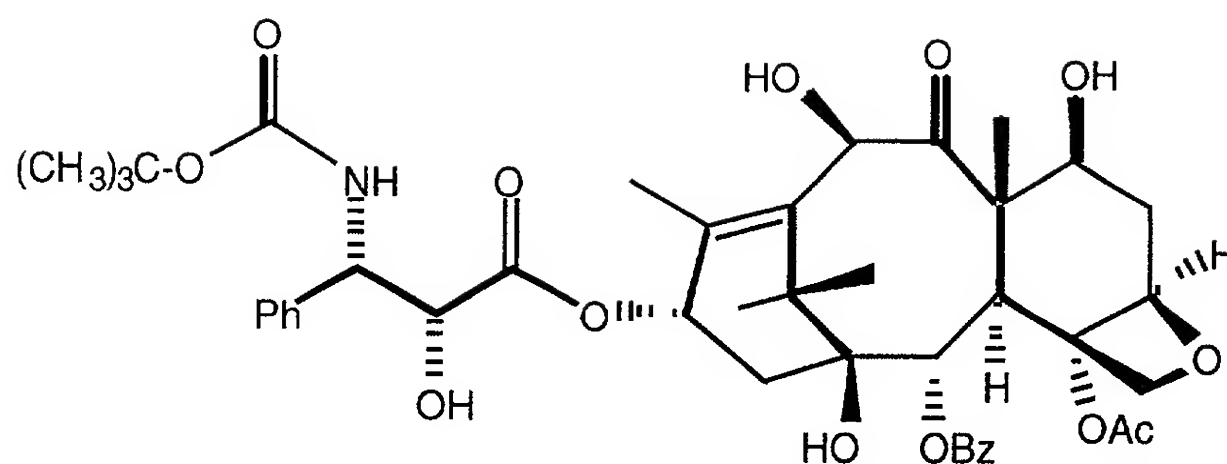
10 The present invention relates to novel oxazolidines  
which find utility as intermediates in the preparation of C-  
13 acyloxy sidechain-bearing taxanes such as paclitaxel and  
analogues thereof. The present invention also relates to  
novel methods of preparing the oxazolidines, as well as to  
15 novel methods of coupling the oxazolidines to form the  
aforementioned sidechain-bearing taxanes.

Background of the Invention

20 Taxanes are diterpene compounds finding utility in  
the pharmaceutical field. For example, paclitaxel (Taxol®),  
a taxane having the structure:



25 where Ph is phenyl, Ac is acetyl and Bz is benzoyl, has been  
found to be an effective anticancer agent. The compound  
taxotere, having the following structure, has also been  
reported for anticancer use:

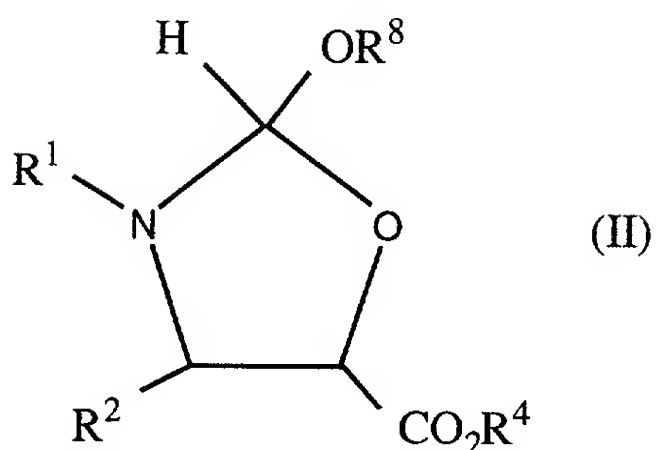
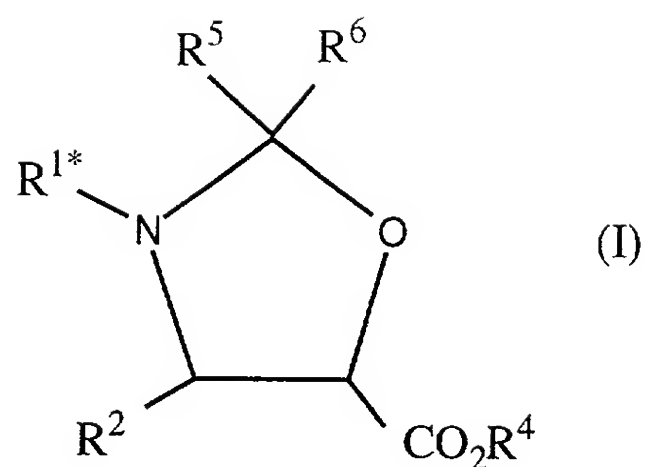


Naturally occurring taxanes such as paclitaxel may be found in plant materials, and have been isolated therefrom. Such taxanes may, however, be present in plant materials in relatively small amounts so that, in the case of paclitaxel, for example, large numbers of the slow-growing yew trees forming a source for the compound may be required. The art has thus continued to search for synthetic, including semi-synthetic routes for the preparation of naturally occurring taxanes such as paclitaxel, as well as routes for the preparation of pharmaceutically useful analogs thereof. In particular, efficient methods for the addition of a C-13 acyloxy sidechain to a taxane core are sought as the presence of the C-13 acyloxy sidechain imparts pharmacological activity or provides a taxane more readily converted to one having such pharmacological activity.

#### Summary of the Invention

The present invention provides novel oxazolidine compounds useful as intermediates for the preparation of C-13 acyloxy sidechain-bearing taxanes. Novel methods for coupling the oxazolidine intermediates of the invention with taxanes containing a hydroxyl group directly bonded at C-13 to provide the aforementioned C-13 acyloxy sidechain-bearing taxanes are also provided, as are methods of preparing the novel oxazolidines of the present invention.

In particular, novel oxazolidines of the formulae I and II are provided:



5 where

$R^1$  is hydrogen, arylcarbonyl, alkoxycarbonyl or alkylcarbonyl;

$R^{1*}$  is hydrogen, arylcarbonyl, alkoxycarbonyl or alkylcarbonyl, with the proviso that  $R^{1*}$  is not  
 10 tert-butoxycarbonyl when  $R^2$  is aryl;

$R^2$  is aryl, heterocyclo or alkyl;

$R^4$  is hydrogen, alkyl, alkenyl, alkynyl, aryl, cycloalkyl, cycloalkenyl, or heterocyclo;

$R^5$  and  $R^6$  are (a) each independently alkyl; or (b) together  
 15 with the carbon atom to which they are bonded, form a cycloalkyl, cycloalkenyl or heterocyclo group; and

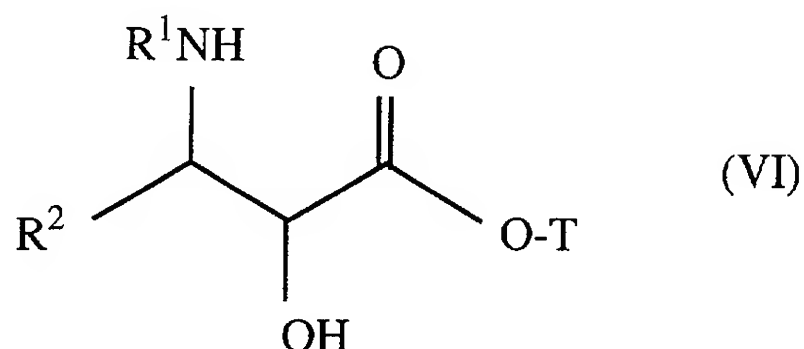
$R^8$  is alkyl or aryl;

and salts thereof.

The novel oxazolidines of the present invention are  
 20 useful as intermediates in the preparation of C-13 acyloxy sidechain-bearing taxanes such as paclitaxel and analogs thereof. Thus, the present invention further provides novel

methods for coupling the intermediates of the formulae I and II with a taxane containing a hydroxyl group directly bonded at C-13 to provide C-13 acyloxy sidechain-bearing taxanes of the following formula VI:

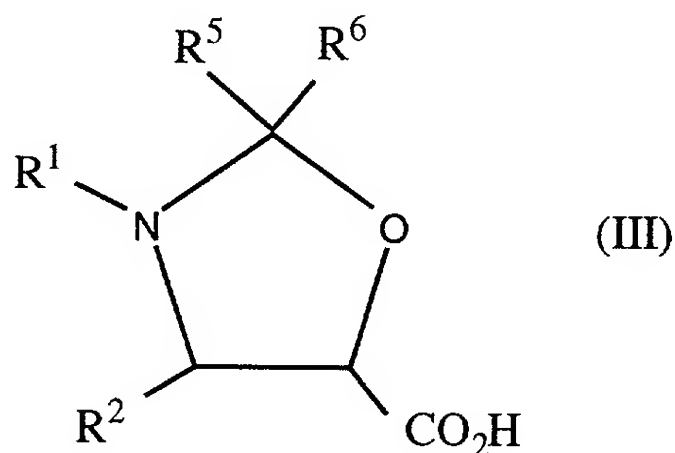
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where  $\text{R}^1$  is hydrogen, arylcarbonyl, alkoxycarbonyl or alkylcarbonyl;  $\text{R}^2$  is aryl, heterocyclo or alkyl; and T is a taxane moiety directly bonded at C-13 of said moiety. Coupling may be achieved by the methods described following.

In one embodiment of the invention, a compound of the formula VI or salt thereof may be prepared by a method comprising the steps of:

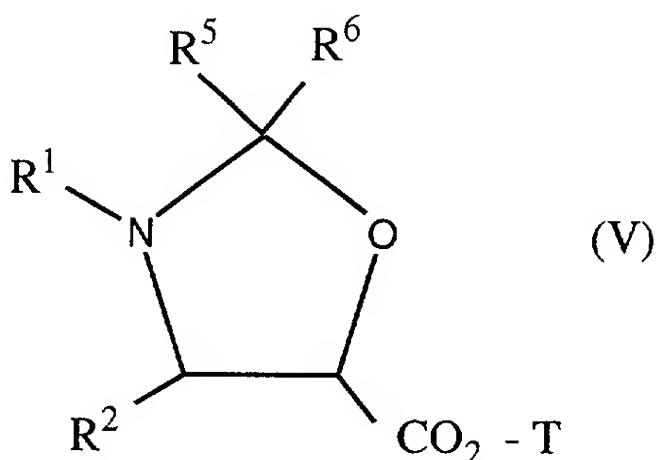
(a) contacting a compound of the following formula III or salt thereof:



with a compound of the following formula IV:



in the presence of a coupling agent, to form a compound of the following formula V or salt thereof:



5

where  $R^1$ ,  $R^2$ ,  $R^5$ ,  $R^6$  and  $T$  are as defined above; and

- (b) contacting said compound of the formula V or salt thereof with a ring-opening agent to form said compound of the formula VI or salt thereof. Each of the steps (a)
- 10 (when  $R^1$  is  $R^{1*}$ ) and (b) of this method are themselves novel methods. Additionally, the compounds of the formulae III and V and salts thereof are novel when  $R^1$  is  $R^{1*}$ .

Compounds of the formula III include compounds of the formula I where  $R^4$  is hydrogen. A compound of the formula I

15 where  $R^4$  is other than hydrogen may be converted to a compound of the formula III where  $R^1$  is  $R^{1*}$  by a novel method comprising the step of hydrolyzing said compound of the formula I where  $R^4$  is other than hydrogen to form said compound of the formula III. Any compound capable of

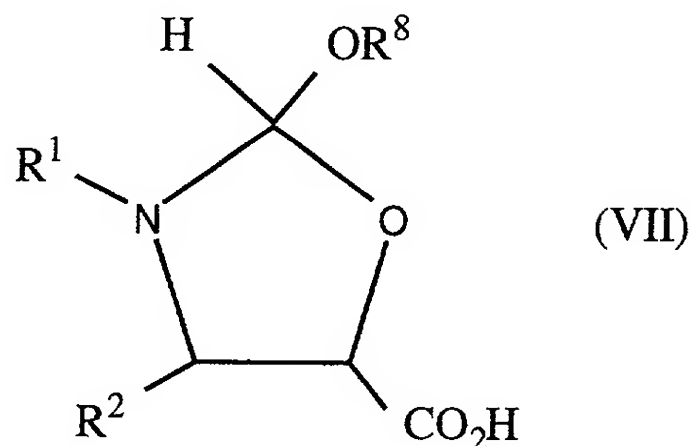
20 effecting the hydrolysis may be employed as the hydrolyzing agent. Exemplary hydrolyzing agents include aqueous bases such as aqueous hydroxides (e.g., metal hydroxides such as barium hydroxide, or preferably, alkali metal hydroxides such as lithium, sodium or potassium hydroxide). Contact

25 with a base provides a carboxylic acid salt of a compound of the formula III. Further contact with an acid, preferably a mineral acid such as HCl, provides a compound of the formula

III where  $R^4$  is hydrogen, that is, which contains a free carboxylic acid group. Compounds of the formula III where  $R^1$  is other than  $R^{1*}$  may be prepared by methods analogous to those methods described herein for the preparation of  
 5 compounds of the formula III where  $R^1$  is  $R^{1*}$ .

In another embodiment of the invention, a compound of the formula VI or salt thereof may be prepared by a method comprising the steps of:

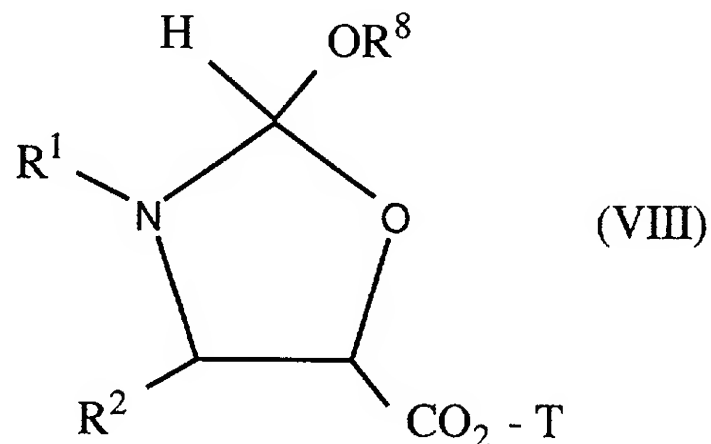
(a) contacting a compound of the following  
 10 formula VII or salt thereof:



with a compound of the following formula IV:  
 15



in the presence of a coupling agent, to form a compound of the following formula VIII or salt thereof:  
 20

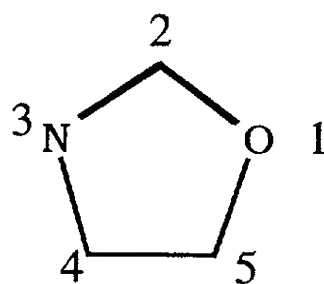


where  $R^1$ ,  $R^2$ ,  $R^8$  and T are as defined above; and

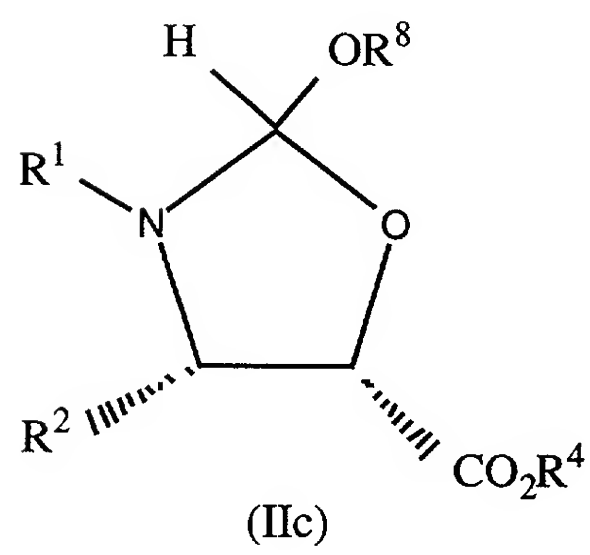
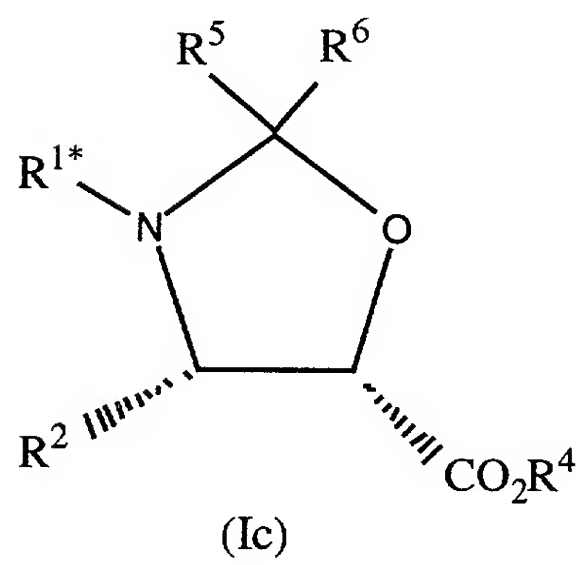
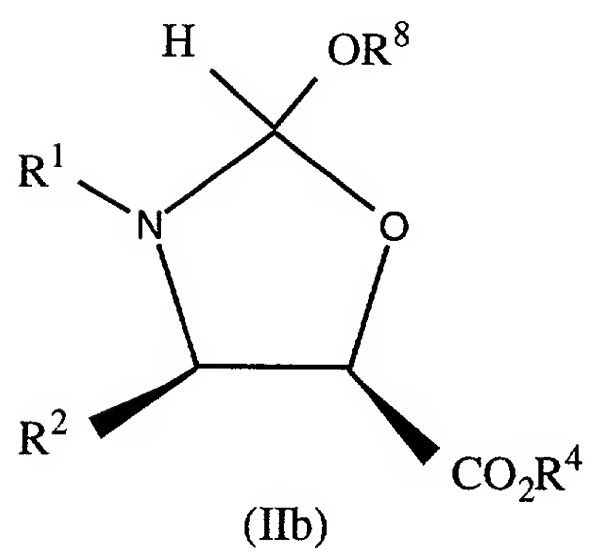
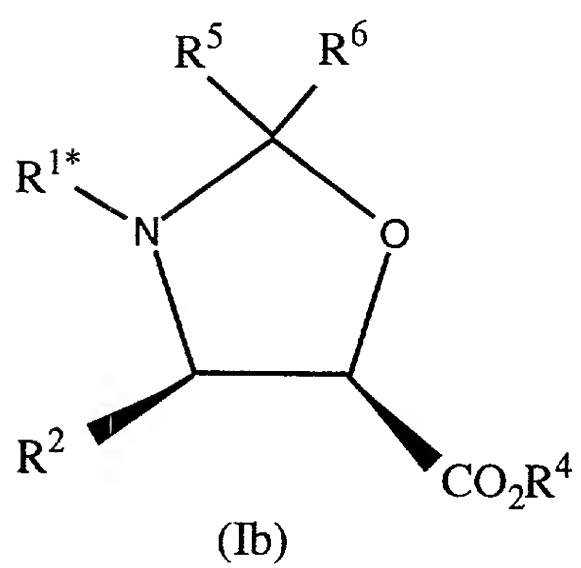
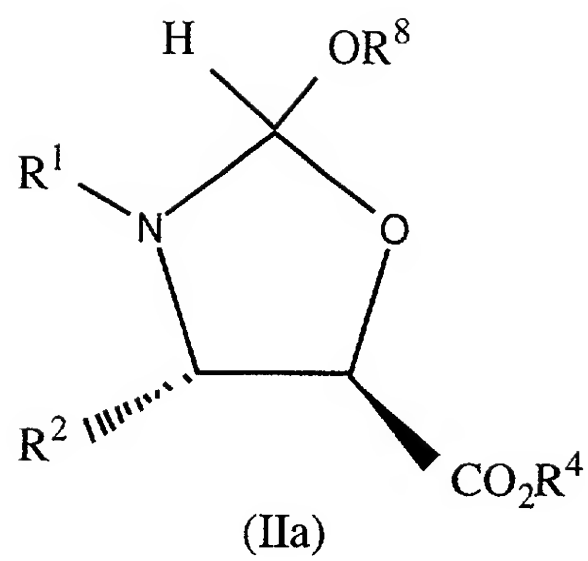
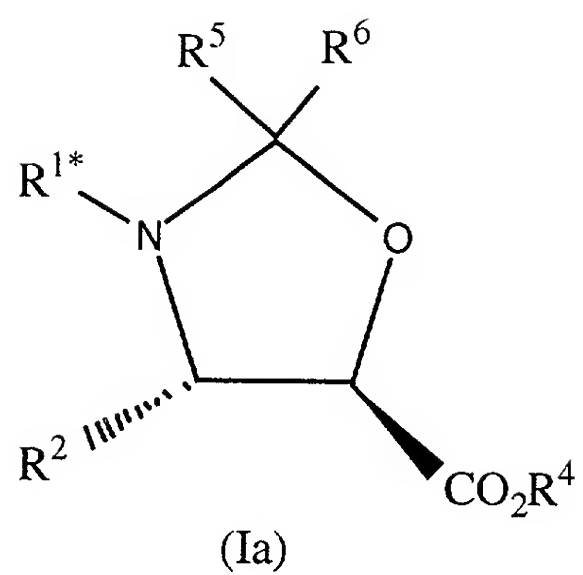
(b) contacting said compound of the formula VIII or salt thereof with a ring-opening agent to form said compound of the formula VI or salt thereof. Each of the steps (a) and (b) of this method are themselves novel methods. Additionally, the compounds of the formulae VII and VIII and salts thereof are novel.

Compounds of the formula VII are compounds of the formula II where  $R^4$  is hydrogen. A compound of the formula II where  $R^4$  is other than hydrogen may be converted to a compound of the formula VII by a novel method comprising the step of hydrolyzing said compound of the formula II where  $R^4$  is other than hydrogen to form said compound of the formula VII. Hydrolysis of a compound of the formula II to form a compound of the formula VII may be conducted as described above for the hydrolysis of a compound of the formula I where  $R^4$  is other than hydrogen to form a compound of the formula III.

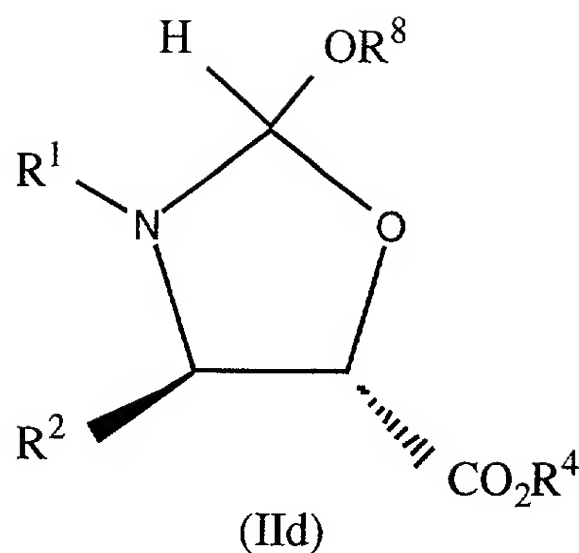
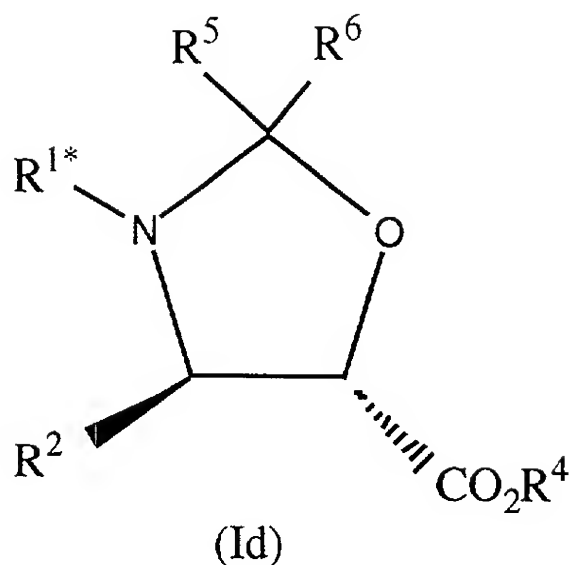
The ring of the present oxazolidine compounds is numbered herein as follows:



With respect to the 4- and 5-position carbon atoms, the oxazolidine compounds of the formulae I and II may exist as the four stereoisomers Ia or IIa, Ib or IIb, Ic or IIc and Id or IId, respectively, as follows:







As the stereochemistry of taxanes may affect their pharmaceutical activity, it is desirable to employ oxazolidine intermediates which will provide the final taxane product with the stereochemistry sought. While the use of stereoisomeric mixtures of a compound of the formula I or II is contemplated herein, the use of a single stereoisomer providing the desired stereochemistry in the final product may achieve a more efficient use of the starting materials and less complicated separation and purification procedures.

#### Detailed Description of the Invention

The present invention is described further as follows.

The terms "alkyl" or "alk", as used herein alone or as part of another group, denote optionally substituted, straight and branched chain saturated hydrocarbon groups, preferably having 1 to 12 carbons in the normal chain. Exemplary unsubstituted such groups include methyl, ethyl, propyl, isopropyl, n-butyl, t-butyl, isobutyl, pentyl, hexyl, isohexyl, heptyl, 4,4-dimethylpentyl, octyl, 2,2,4-trimethylpentyl, nonyl, decyl, undecyl, dodecyl and the like. Exemplary substituents may include one or more of the following groups: halo, alkoxy, alkylthio, alkenyl, alkynyl, aryl, cycloalkyl, cycloalkenyl, hydroxy or protected hydroxy, carboxyl (-COOH), alkyloxycarbonyl,

alkylcarbonyloxy, carbamoyl ( $\text{NH}_2\text{-CO-}$ ), amino ( $\text{-NH}_2$ ), mono- or dialkylamino, or thiol ( $\text{-SH}$ ).

The terms "lower alk" or "lower alkyl", as used herein, denote such optionally substituted groups as described above for alkyl having 1 to 6 carbon atoms in the normal chain.

The terms "alkoxy" or "alkylthio", as used herein, denote an alkyl group as described above bonded through an oxygen linkage ( $\text{-O-}$ ) or a sulfur linkage ( $\text{-S-}$ ), respectively. The term "alkyloxycarbonyl", as used herein, denotes an alkoxy group bonded through a carbonyl group. The term "alkylcarbonyl", as used herein, denotes an alkyl group bonded through a carbonyl group. The term "alkylcarbonyloxy", as used herein, denotes an alkylcarbonyl group which is bonded through an oxygen linkage. The terms "monoalkylamino" or "dialkylamino" denote an amino group substituted by one or two alkyl groups as described above, respectively.

The term "alkenyl", as used herein alone or as part of another group, denotes such optionally substituted groups as described for alkyl, further containing at least one carbon to carbon double bond. Exemplary substituents include one or more alkyl groups as described above, and/or one or more groups described above as alkyl substituents.

The term "alkynyl", as used herein alone or as part of another group, denotes such optionally substituted groups as described for alkyl, further containing at least one carbon to carbon triple bond. Exemplary substituents include one or more alkyl groups as described above, and/or one or more groups described above as alkyl substituents.

The term "cycloalkyl", as used herein alone or as part of another group, denotes optionally substituted, saturated cyclic hydrocarbon ring systems, preferably containing 1 to 3 rings and 3 to 7 carbons per ring.

Exemplary unsubstituted such groups include cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, cycloheptyl, cyclooctyl, cyclodecyl, cyclododecyl, and adamantyl.

Exemplary substituents include one or more alkyl groups as described above, and/or one or more groups described above as alkyl substituents.

The term "cycloalkenyl", as used herein alone or as part of another group, denotes such optionally substituted groups as described above for cycloalkyl, further containing at least one carbon to carbon double bond forming a partially unsaturated ring. Exemplary substituents include one or more alkyl groups as described above, and/or one or more groups described above as alkyl substituents.

The terms "ar" or "aryl", as used herein alone or as part of another group, denote optionally substituted, homocyclic aromatic groups, preferably containing 1 or 2 rings and 6 to 12 ring carbons. Exemplary unsubstituted such groups include phenyl, biphenyl, and naphthyl. Exemplary substituents include one or more, preferably three or fewer, nitro groups, alkyl groups as described above, and/or groups described above as alkyl substituents.

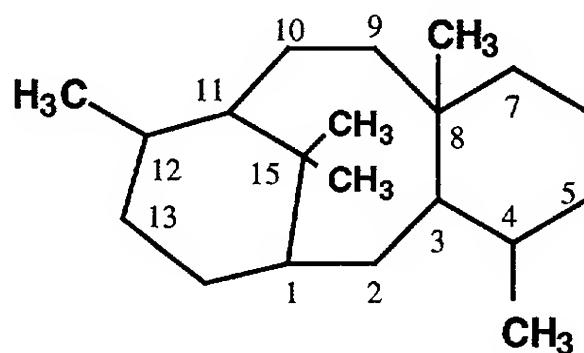
The term "arylcarbonyl", as used herein alone or as part of another group, denotes an aryl group as described above bonded through a carbonyl group.

The terms "heterocyclo" or "heterocyclic", as used herein alone or as part of another group, denote optionally substituted, fully saturated or unsaturated, aromatic or non-aromatic cyclic groups having at least one heteroatom in at least one ring, preferably monocyclic or bicyclic groups having 5 or 6 atoms in each ring. The heterocyclo group may, for example, have 1 or 2 oxygen atoms, 1 or 2 sulfur atoms, and/or 1 to 4 nitrogen atoms in the ring. Each heterocyclo group may be bonded through any carbon or heteroatom of the ring system. Exemplary heterocyclo groups

include the following: thienyl, furyl, pyrrolyl, pyridyl, imidazolyl, pyrrolidinyl, piperidinyl, azepinyl, indolyl, isoindolyl, quinolinyl, isoquinolinyl, benzothiazolyl, benzoxazolyl, benzimidazolyl, benzoxadiazolyl, benzofurazanyl, and especially, tetrahydropyranyl (e.g. 4-tetrahydropyranyl). Exemplary substituents include one or more alkyl groups as described above, and/or one or more groups described above as alkyl substituents.

The terms "halogen" or "halo", as used herein alone or as part of another group, denote chlorine, bromine, fluorine, and iodine.

The term "taxane moiety", as used herein, denotes moieties containing the core structure:



which core structure may be substituted and which may contain ethylenic unsaturation in the ring system thereof. Such moieties having an oxetane ring fused at the 4- and 5-positions, and an ethylenic double bond between C-11 and C-12, such as are found in paclitaxel, are preferred.

The term "taxane", as used herein, denotes compounds containing a taxane moiety as described above. The term "C-13 acyloxy sidechain-bearing taxane", as used herein, denotes compounds containing a taxane moiety as described above, further containing an acyloxy sidechain directly bonded to said moiety at C-13 through the oxygen of the oxy group of the acyloxy substituent.

The term "hydroxy (or hydroxyl) protecting group", as used herein, denotes any group capable of protecting a free hydroxyl group which, subsequent to the reaction for which

it is employed, may be removed without destroying the remainder of the molecule. Such groups, and the synthesis thereof, may be found in "Protective Groups in Organic Synthesis" by T.W. Greene, John Wiley and Sons, 1981, or  
5 Fieser & Fieser. Exemplary hydroxyl protecting groups include methoxymethyl, 1-ethoxyethyl, 1-methoxy-1-methylethyl, benzyloxymethyl, ( $\beta$ -trimethylsilyl-ethoxy)methyl, tetrahydropyranyl, 2,2,2-tri-chloroethoxycarbonyl, t-butyl(diphenyl)silyl, trialkylsilyl,  
10 trichloromethoxycarbonyl, and 2,2,2-trichloroethoxymethyl.

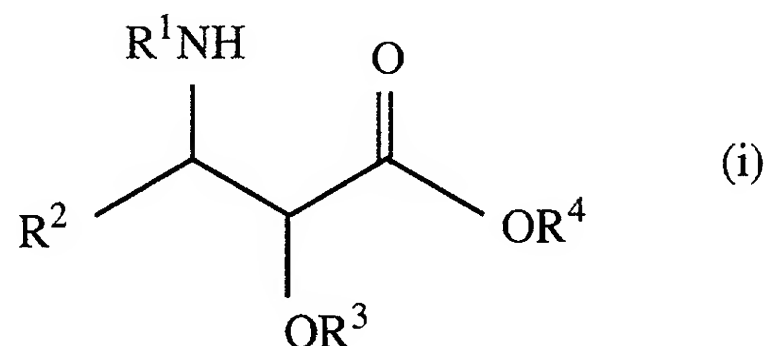
The term "salt", as used herein, includes salts with organic and/or inorganic acids and/or bases.

The term "acyl", as used herein alone or as part of another group, denotes the moiety formed by removal of the  
15 hydroxyl group from the group -COOH of an organic carboxylic acid. The term "acyloxy", as used herein alone or as part of another group, denotes an acyl group as described above bonded through an oxygen linkage (-O-).

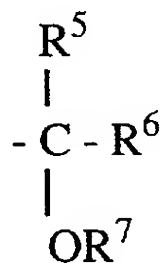
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Preparation of Oxazolidines of the  
Formulae I and II

The oxazolidines of the formulae I and II and salts thereof may be prepared starting with a compound of the following formula i:



where  $\text{R}^1$  is hydrogen, arylcarbonyl, alkoxycarbonyl or alkylcarbonyl;  $\text{R}^2$  is aryl, heterocyclo or alkyl;  $\text{R}^4$  is hydrogen, alkyl, alkenyl, alkynyl, aryl, cycloalkyl, cycloalkenyl or heterocyclo; and where  $\text{R}^3$  is hydrogen or the group  $\text{R}^3\text{P}$ , where  $\text{R}^3\text{P}$  is the group:

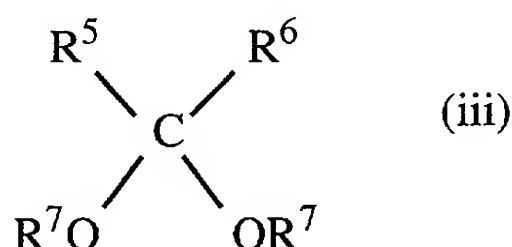
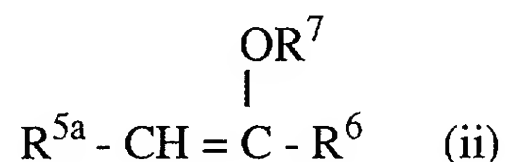


where  $\text{R}^5$  and  $\text{R}^6$  are as defined above, and  $\text{R}^7$  is alkyl or aryl. Compounds of the formula i may be prepared as described in, or by methods analogous to those described in, U.S. Application Serial No. 07/975,453, filed November 12, 1992 (Attorney Docket No. LD54), or U.S. Application Serial No. 08/263,869, filed June 21, 1994 (Attorney Docket No. LD68), or as described below.

Compounds of the formula I and salts thereof may be prepared from compounds of the formula i and salts thereof where  $\text{R}^1$  is  $\text{R}^{1*}$  by a novel method comprising the step of

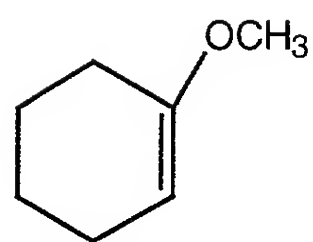
contacting said compound of the formula i or salt thereof with an acid catalyst, and additionally, where  $R^3$  in said compound of the formula i or salt thereof is hydrogen, with a compound of the formula ii or iii described following.

- 5 The aforementioned compounds of the formulae ii and iii have the following structures:

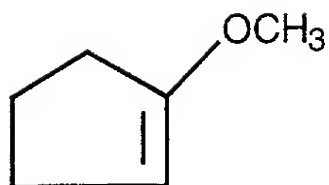


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- where  $R^5$ ,  $R^6$  and  $R^7$  are as defined above, and where  $R^{5a}$  (i) is a group such that  $R^{5a}-CH_2-$  is  $R^5$  or (ii) forms, together with  $R^6$  and the atoms to which  $R^{5a}$  and  $R^6$  are bonded, a
- 15 cycloalkenyl or heterocyclo group containing at least one carbon to carbon double bond. Compounds of the formulae ii and iii are commercially available or may readily be prepared by known methods. Exemplary compounds of the formula ii include the compounds:



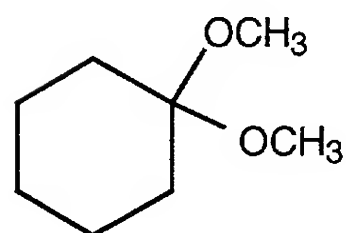
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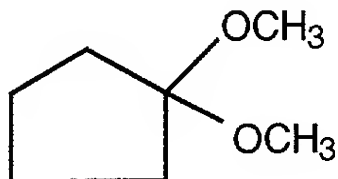
, or, most preferably,

2-methoxypropene. Exemplary compounds of the formula iii include the compounds: dimethoxypropane,

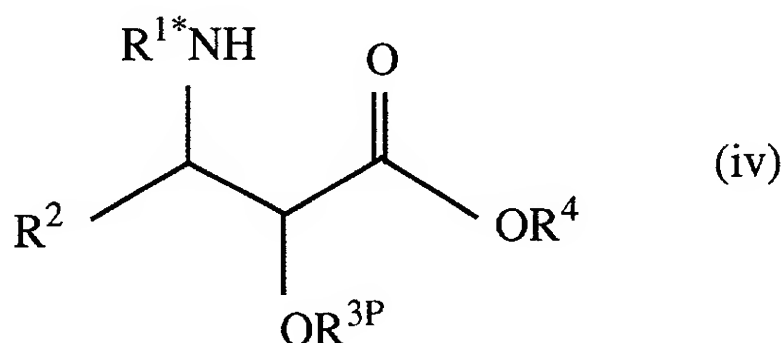
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or



Novel compounds of the following formula iv and salts thereof:

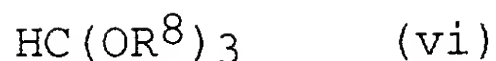


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where  $R^{1*}$ ,  $R^2$ ,  $R^{3P}$  and  $R^4$  are as defined above may be formed as intermediates in the aforementioned method when a compound of the formula i or salt thereof in which  $R^3$  is hydrogen is contacted with the compound of the formula ii or iii. In the presence of acid catalyst, the compound iv or salt thereof undergoes conversion to a compound of the formula I or salt thereof.

Compounds of the formula II and salts thereof may be prepared from compounds of the formula i and salts thereof by a novel method comprising the step of contacting a compound of the formula i or salt thereof where  $R^3$  is hydrogen, in the presence of an acid catalyst, with a compound of the following formula vi:

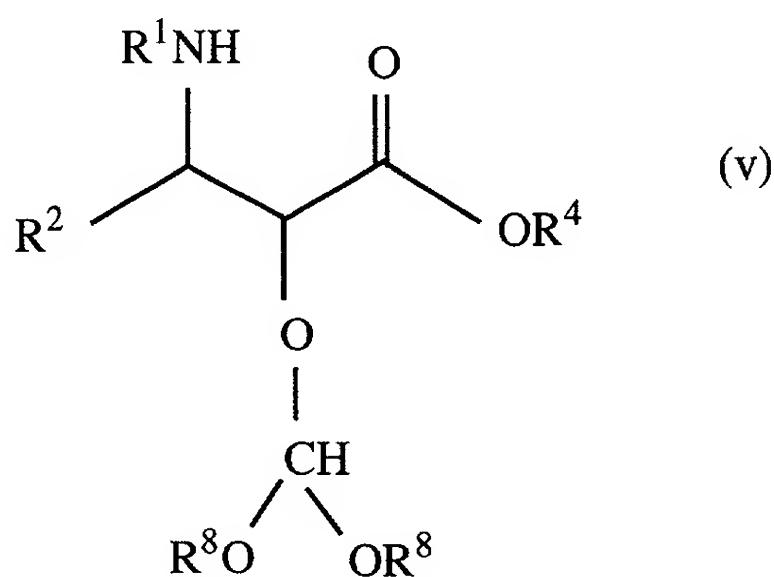




where  $\text{R}^8$  is as defined above. Compounds of the formula vi  
 5 are commercially available or may readily be prepared by  
 known methods. Exemplary compounds of the formula vi  
 include trimethoxymethane and triethoxymethane.

Novel compounds of the following formula v and salts  
 thereof:

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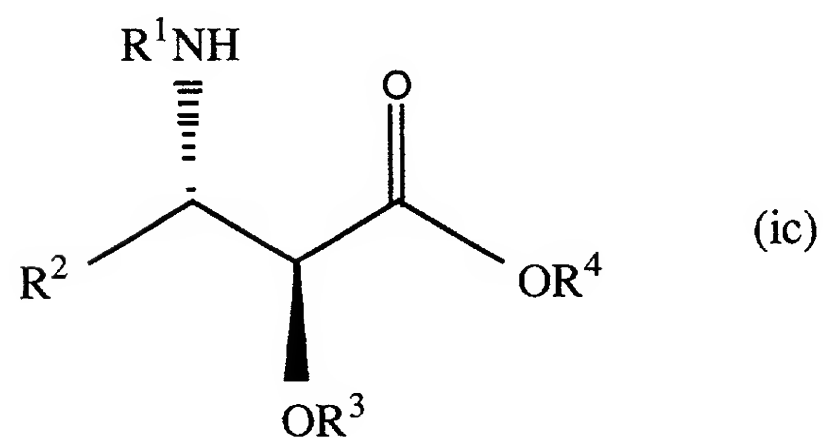
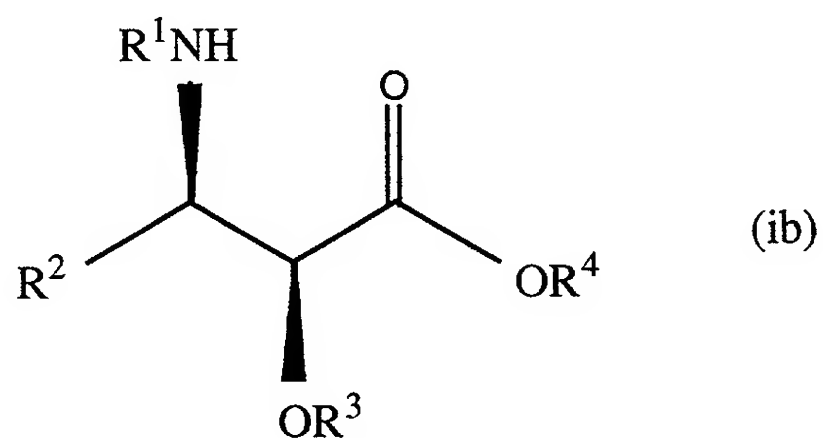
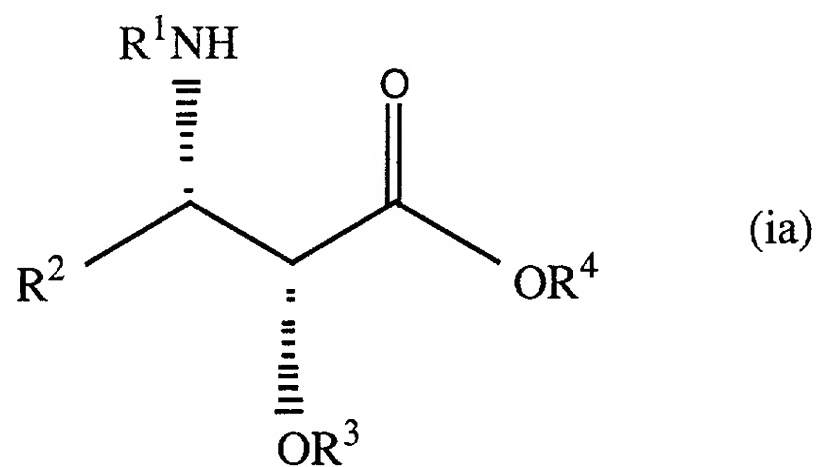


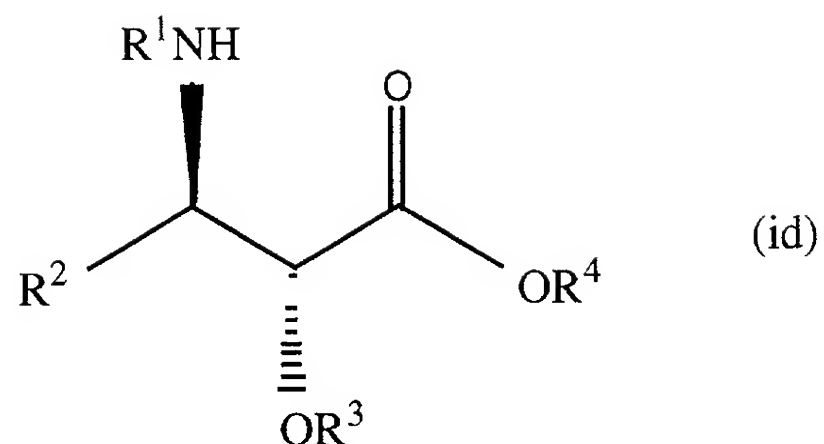
where  $\text{R}^1$ ,  $\text{R}^2$ ,  $\text{R}^4$  and  $\text{R}^8$  are as defined above may be formed  
 as intermediates in the aforementioned method. In the  
 15 presence of acid catalyst, the compound v or salt thereof  
 undergoes conversion to a compound of the formula II or salt  
 thereof.

For the conversion of a compound i to a compound I or  
 II as described above, the present methods employ an "acid  
 20 catalyst". Any acid catalyzing the method referred to may  
 suitably be employed as the acid catalyst, with organic  
 sulfonic acids (that is, organic acids containing the group  
 $\text{SO}_2\text{O}^-$ ) or sulfonates, or mineral acids being preferred.  
 Particularly preferred such acid catalysts include  
 25 pyridinium p-toluene sulfonate (PPTS), toluene sulfonic  
 acid, camphor sulfonic acid, and the like.

The compounds of the formula i and salts thereof may exist as four stereoisomers with respect to the carbon atoms at those positions corresponding to the 4- and 5-position carbon atoms of the compounds of the formulae I and II.

- 5 These stereoisomers are the following compounds of the formulae ia, ib, ic and id:





A desired stereoisomer of a compound of the formula I  
 or II or salt thereof may be prepared by the methods  
 5 described above by employing the appropriate stereoisomer of  
 the starting compound of the formula i or salt thereof.  
 Thus, use of a compound ia can provide a compound Ia or IIa,  
 use of a compound ib can provide a compound Id or IIId, use  
 of a compound ic can provide a compound Ic or IIc, and use  
 10 of a compound id can provide a compound Ib or IIb. It is  
 preferred to employ a single stereoisomer of the starting  
 compound i or salt thereof in the above described methods,  
 although stereoisomeric mixtures may also be employed. Use  
 of a compound ia to prepare a compound Ia or IIa is  
 15 particularly preferred.

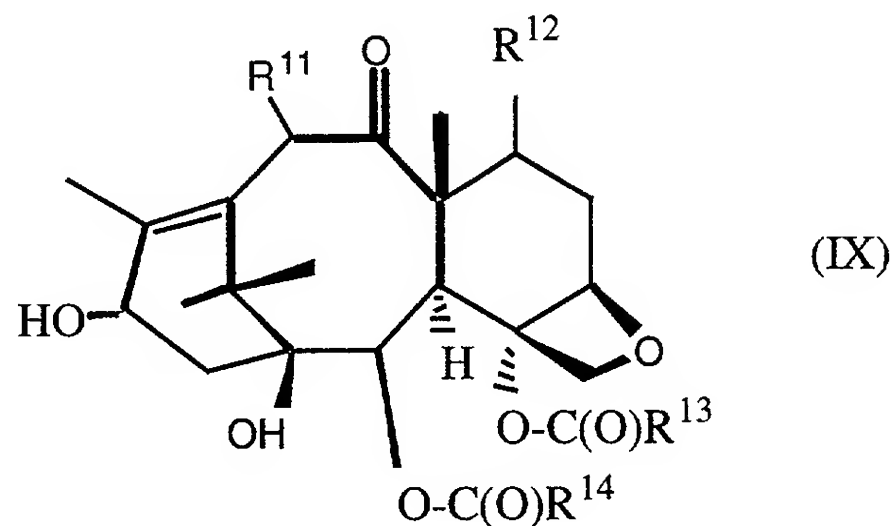
#### Coupling to Prepare Oxazolidine

##### Sidechain-bearing Taxanes

An oxazolidine sidechain-bearing taxane of the  
 20 formula V or VIII or salt thereof may be prepared by a  
 method comprising the step of contacting an oxazolidine  
 compound of the formula III or VII, respectively, or salt  
 thereof, in the presence of a coupling agent, with a taxane  
 of the formula IV having a hydroxyl group directly bonded to  
 25 C-13 thereof. The taxane starting material of the formula  
 IV is preferably a compound such as those described in  
 European Patent Publication No. 400,971, incorporated herein  
 by reference, or a compound such as those described in U.S.  
 Patent Application Serial No. 08/995,443, filed December 23,

1992 by Poss et al., or continuation-in-part thereof U.S. Patent Application Serial No. 08/171,792, filed December 22, 1993, both also incorporated herein by reference. Exemplary such taxanes include those of the following formula IX:

5



where

R<sup>11</sup> is hydrogen, hydroxyl, R<sup>15</sup>-O-, R<sup>16</sup>-C(O)-O-, or  
 10 R<sup>16</sup>-O-C(O)-O-;

R<sup>12</sup> is hydrogen, hydroxyl, fluoro, R<sup>15</sup>-O-,  
 R<sup>16</sup>-C(O)-O- or R<sup>16</sup>-O-C(O)-O-;

R<sup>13</sup> and R<sup>14</sup> are independently hydrogen, alkyl, alkenyl,  
 alkynyl, cycloalkyl, cycloalkenyl, aryl, or  
 15 heterocyclo;

R<sup>15</sup> is a hydroxyl protecting group; and

R<sup>16</sup> is hydrogen, alkyl, alkenyl, alkynyl, cycloalkyl,  
 cycloalkenyl, aryl or heterocyclo,  
 or salts thereof.

20 All stereoconfigurations of the unspecified chiral centers of the compound of the formula IX are contemplated for use in the coupling method of the present invention. The use of a single stereoisomer is preferred, although mixtures thereof may be employed. 7-Trialkylsilyl baccatin  
 25 III compounds are preferably employed as the compounds of

the formula IV, most preferably, 7-trimethylsilyl baccatin III or 7-triethylsilyl baccatin III.

Any compound capable of effecting the coupling reaction may be employed as the coupling agent of the present invention. Exemplary coupling agents include one or more compounds forming an activated oxazolidine ester (for example, 1-hydroxybenzotriazole or N-hydroxysuccinimide, both of these with dicyclohexylcarbodiimide (DCC)) or anhydride (for example, an acid chloride such as pivaloyl chloride or bis(2-oxo-3-oxazolidinyl)-phosphinic chloride) when contacted with an oxazolidine of the formula III or VII, particularly coupling agents comprising a compound such as a carbodiimide (e.g., dicyclohexylcarbodiimide (DCC), 1,3-diisopropylcarbodiimide (DIC), or 1-(3-dimethyl-aminopropyl)-3-ethyl-carbodiimide hydrochloride), bis(2-oxo-3-oxazolidinyl)phosphinic chloride), carbonyl diimidazole (CDI), pivaloyl chloride, or 2,4,6-trichlorobenzoyl chloride; wherein the aforementioned compounds are preferably employed together with a compound such as 1-hydroxybenzotriazole (HOBt) or N-hydroxysuccinimide (HO-Su), or an amine such as triethylamine, pyridine or pyridine substituted at the 4-position with  $-N(R^{17})(R^{18})$ , where  $R^{17}$  and  $R^{18}$  are independently selected from alkyl, alkenyl, alkynyl, cycloalkyl, cycloalkenyl or heterocyclo (to form a compound such as 4-dimethylaminopyridine (DMAP)), or where  $R^{17}$  and  $R^{18}$ , together with the nitrogen atom to which they are bonded, form a heterocyclo group (to form a compound such as 4-morpholinopyridine or 4-pyrrolidinopyridine).

Ring Opening to Form Taxanes of the  
Formula VI

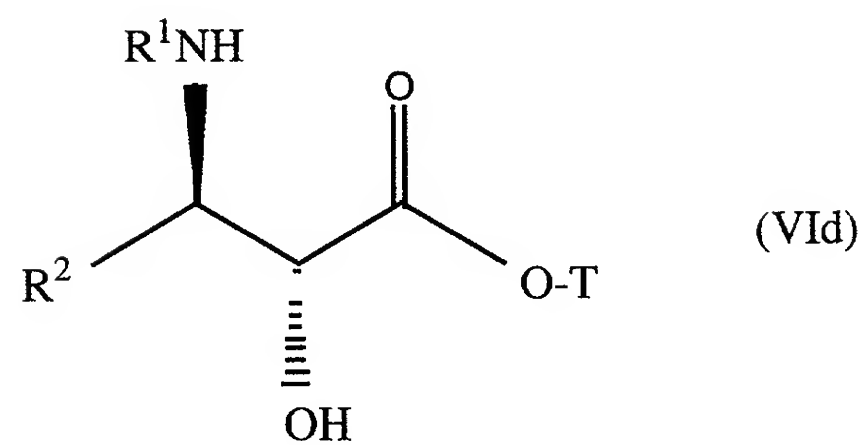
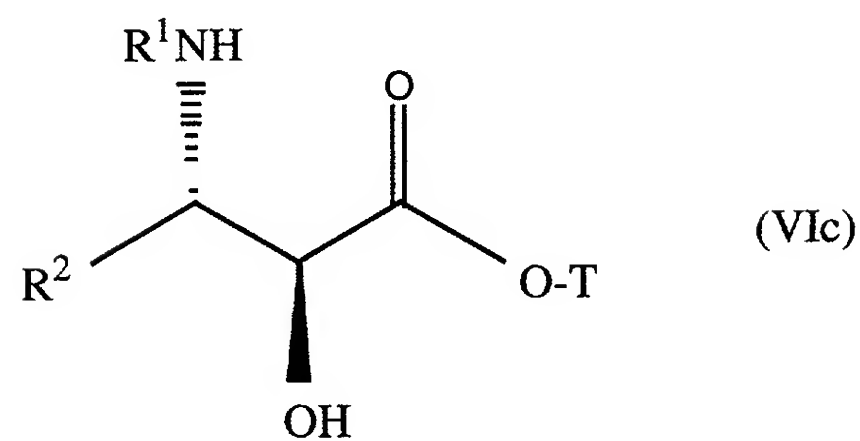
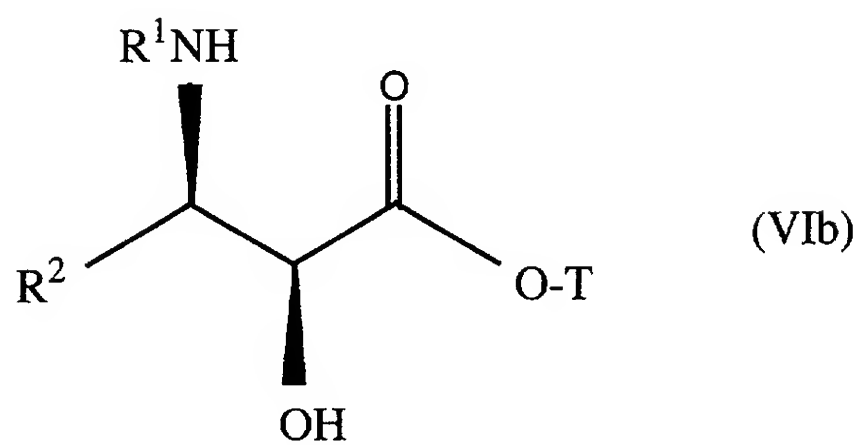
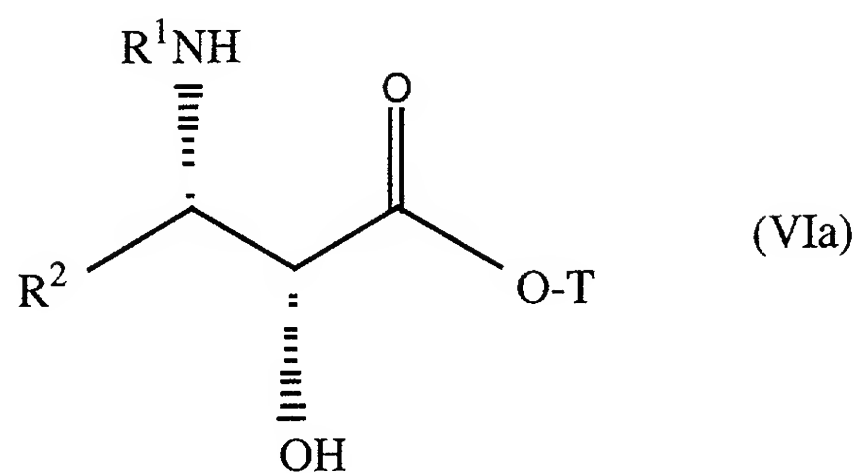
A sidechain-bearing taxane of the formula VI or salt thereof may be prepared from an oxazolidine sidechain-bearing taxane of the formula V or VIII or salt thereof, by a method comprising the step of contacting said taxane of the formula V or VIII or salt thereof with a ring-opening agent capable of opening the ring of the oxazolidine group bonded through C-13 of the taxane moiety of said taxane compound to form said taxane compound of the formula VI or salt thereof.

A preferred class of ring-opening agents for the conversion of a compound V or salt thereof to a compound VI or salt thereof are Lewis acids which preferably cause minimal or, most preferably, no decomposition of the compounds V or VI or salts thereof ("mild Lewis acids"). Any Lewis acid capable of effecting the aforementioned ring opening may be employed in the method of the present invention. Exemplary such agents include palladium containing agents such as  $\text{Pd}(\text{CH}_3\text{CN})_2\text{Cl}_2$ .

A preferred class of ring-opening agents for the conversion of a compound VIII or salt thereof to a compound VI or salt thereof are protic acids. Any protic acid capable of effecting the aforementioned ring opening may be employed in the method of the present invention. Exemplary such ring-opening acids include organic carboxylic acids, such as acetic acid or trifluoroacetic acid, and/or mineral acids such as hydrochloric acid, hydrofluoric acid or sulfuric acid, in water.

The compounds of the formula VI and salts thereof may exist as four stereoisomers with respect to the carbon atoms at those positions corresponding to the 4- and 5-position carbon atoms of the compounds of the formulae I and II.

These stereoisomers are the following compounds of the formulae VIa, VIb, VIc and VIId:



A desired stereoisomer of the compound of the formula VI or salt thereof may be prepared by the methods described above by employing the appropriate stereoisomer of the starting compound of the formula III or VII or salt thereof.

5 Using the designations "a" through "d" to refer to the stereoisomers of the formulae III and VII as are used for the compounds I and II above: use of a compound IIIa or VIIa will provide a compound VIa; use of a compound IIId or VIId will provide a compound VId; use of a compound IIIc or VIIC will provide, predominantly, a compound VIa along with a  
10 minor amount of a compound VIc; and use of a compound IIIB or VIIB will provide, predominantly, a compound VIB along with a minor amount of a compound VID. It is preferred to employ a single stereoisomer of the starting compound III or  
15 VII or salt thereof in the above described methods, although stereoisomeric mixtures may also be employed. Use of a compound Ia to prepare a compound VIa is particularly preferred.

A preferred embodiment of the present invention  
20 further comprises the step of deprotecting one or more groups, particularly to free hydroxyl groups, on the taxane moiety to prepare taxanes of the formula VI or salts thereof. Deprotection may, for example, be conducted prior or subsequent to, or simultaneously with, the aforementioned  
25 ring opening methods by use of a deprotection agent. Any compound capable of deprotection may be employed as the deprotection agent. For example, acids such as hydrofluoric acid or aqueous protic acids, or tetra-alkylammonium  
fluorides such as tetra-n-butylammonium fluoride, may be  
30 employed for removal of silyl protecting groups; benzyl protecting groups may be removed by hydrogenation; trichloroethoxycarbonyl protecting groups may be removed by contact with zinc; and acetal or ketal protecting groups may be removed by the use of protic acids or Lewis acids.



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A particularly preferred embodiment of the present invention comprises simultaneous ring opening and deprotection of one or more hydroxyl groups on the taxane ring structure, particularly at C-7, such as by the use of an acid (e.g., a mineral acid such as hydrochloric acid) capable of effecting both ring opening and deprotection simultaneously. Thus, for example, use of an acid agent under reaction conditions described above for ring opening may allow simultaneous ring opening and deprotection of cleavable hydroxyl protecting groups at C-7 such as trialkylsilyl (e.g. trimethylsilyl or triethylsilyl).

#### Preferred Reaction Conditions

The methods of the present invention may be conducted under any conditions, such as temperature, pressure and time, and using the appropriate starting materials and catalysts in any relative amount, effective to achieve the desired conversion. Similarly, a solvent may be employed if desired and may be selected from any material in which the conversion may be conducted, including inorganic (e.g., aqueous) or organic (e.g., acetone, dimethylformamide, tetrahydrofuran, methylene chloride, acetonitrile, benzene or toluene) liquids or mixtures thereof. Solvents are preferably employed which are inert to the reaction.

The products of the methods of the present invention may be isolated and purified by any suitable methodology such as extraction, distillation, crystallization, column chromatography, and the like.

Particularly preferred reaction conditions for conducting various methods described herein are set forth in the following Tables 1 to 6.

Salts or solvates such as hydrates of reactants or products may be employed or prepared as appropriate in any of the methods of the present invention. Unless otherwise

indicated, reference to a compound herein is understood to include salts and/or solvents thereof.

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Table 1

Preferred Reaction Conditions for the Preparation of a  
Compound of the Formula I

starting compounds	i; and ii or iii when $R^3 = H$ in i
molar ratio of ii or iii:i	molar excess of ii or iii:i
catalyst	acid catalyst
molar ratio of catalyst:i	0.03:1 to 0.1:1
temperature (°C)	80 to 110
pressure (atm)	atmospheric
atmosphere	gas inert to reaction
solvent	organic
amount of solvent (weight of i: volume of solvent)	1 g:50 ml to 1 g:100 ml

5

Compound iv can be formed as an intermediate and converted to a compound of the formula I *in situ* due to the presence of acid catalyst, or contacted with acid catalyst in a separate step.

10

Table 2

Preferred Reaction Conditions for the Preparation of a  
Compound of the Formula II

starting compound	i ( $R^3 = H$ ) and vi
molar ratio of vi:i	molar excess of vi:i
catalyst	acid catalyst
molar ratio of catalyst:i	0.03:1 to 0.1:1
temperature ( $^{\circ}C$ )	80 to 110
pressure (atm)	atmospheric
atmosphere	gas inert to reaction
solvent	organic
amount of solvent (weight of i:volume of solvent)	1 g:50 ml to 1 g:100 ml

5

Compound v can be formed as an intermediate and converted to a compound of the formula II.

Table 3Preferred Reaction Conditions for the Preparation of a  
Compound of the Formula III or VII

starting compound	I or II (where $R^4 \cdot H$ ); and base
molar ratio of base:I or II	1:1 to 1.05:1
further starting material	acid
molar ratio of acid:I or II	1:1 to 1.05:1
temperature ( $^{\circ}\text{C}$ )	room ( $\sim 25^{\circ}\text{C}$ )
pressure (atm)	atmospheric
atmosphere	gas inert to reaction
solvent	aqueous/organic mixture
amount of solvent (weight of I or II: volume of solvent)	1 g:50 ml to 1 g:100 ml

5

As described above, use of the base only can provide a formula III or VII salt; further use of an acid provides the free carboxylic acid.

Table 4  
Preferred Reaction Conditions for the Preparation of a  
Compound of the Formula V or VIII

starting compound	III or VII; and IV
molar ratio of III or VII:IV	molar excess of III or VII:IV, especially molar ratio of 1.1:1 to 1.5:1
coupling agent	carbodiimide or phosphinic chloride and amine
molar ratio of carbodiimide or phosphinic chloride:III or VII	1.5:1 to 1:1
molar ratio of amine:III or VII	0.5:1 to 1:1
temperature (°C)	60 to 100
pressure (atm)	atmospheric
atmosphere	gas inert to reaction
solvent	organic
amount of solvent (weight of III or VII: volume of solvent)	1 g:5 ml to 1 g:10 ml

Table 5

Preferred Reaction Conditions for the Preparation of a  
Compound of the Formula VI Using Protic Acid

starting compound	VIII; and protic acid (especially, aqueous protic acid)
molar ratio of acid:VIII	molar excess of acid:VIII
temperature (°C)	0 to 25
pressure (atm)	atmospheric
atmosphere	gas inert to reaction
solvent	aqueous/organic
amount of solvent (weight of VIII: volume of solvent)	1 g:10 ml to 1 g:20 ml

5

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Table 6

Preferred Reaction Conditions for the Preparation of a  
Compound of the Formula VI Using Lewis acid

starting compound	V; and Lewis acid (especially, mild Lewis acid)
molar ratio of Lewis acid:V	0.02:1 to 0.1:1
temperature (°C)	room (~25°C)
pressure (atm)	atmospheric
atmosphere	gas inert to reaction
solvent	organic
amount of solvent (weight of V: volume of solvent)	1 g:5 ml to 1 g:15 ml

5

Preferred Groups

Preferred groups forming part of compounds used or  
10 prepared by the present invention are those where:

$R^1$  and  $R^{1*}$  are each independently arylcarbonyl  
(especially benzoyl) or alkyloxycarbonyl (especially  
unsubstituted lower alkyloxycarbonyl such as tert-  
butoxycarbonyl);

15  $R^2$  is phenyl, thienyl or furyl;

$R^3$  is hydrogen or  $R^{3P}$  where  $R^5$ ,  $R^6$  and  $R^7$  are each  
independently unsubstituted lower alkyl (especially, methyl  
or ethyl);

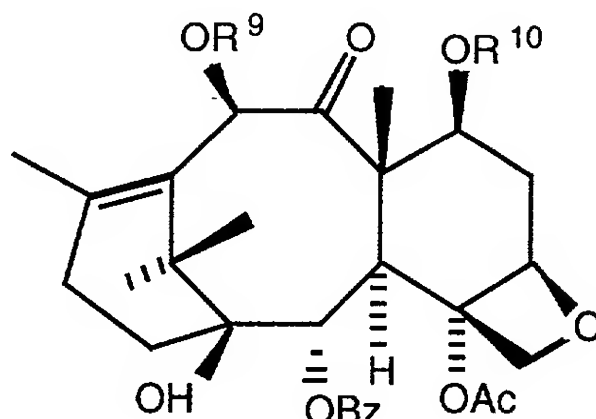
20  $R^4$  is hydrogen or unsubstituted lower alkyl  
(especially, methyl or ethyl);



R<sup>5</sup>, R<sup>6</sup> and R<sup>7</sup> are each independently unsubstituted lower alkyl (especially, methyl or ethyl);

R<sup>8</sup> is unsubstituted lower alkyl (especially methyl or ethyl); and

5 T is the moiety:



where

10 R<sup>9</sup> is hydrogen, alkylcarbonyl, or a hydroxyl protecting group, especially acetyl; and

R<sup>10</sup> is hydrogen or a hydroxyl protecting group, especially a trialkylsilyl group such as triethylsilyl or trimethylsilyl.

#### C-13 Acyloxy Sidechain-bearing Taxanes

15 The addition of a C-13 acyloxy sidechain as described herein, in and of itself, may impart an increased or more desirable pharmacological activity to the taxane product, or may form a taxane product which is more readily converted to a taxane having an increased or more desirable

20 pharmacological activity than the starting compound.

Exemplary taxanes which may be prepared by the present methods for the preparation of sidechain-bearing taxanes include those taxanes described in European Patent Publication No. 400,971, and U.S. Patent Applications

25 07/995,443, filed December 23, 1992 and 08/171,792, filed December 22, 1993, all incorporated herein by reference. It is preferred to ultimately prepare taxotere or, most preferably, paclitaxel according to the methods of the present invention.

Pharmacologically active taxanes such as paclitaxel may be used as antitumor agents to treat patients suffering from cancers such as breast, ovarian, colon or lung cancers, melanoma and leukemia.

5           As can be appreciated, the oxazolidines, taxanes and other compounds described herein may be present in more than one stereoisomeric form. All stereoisomers of the compounds described herein are contemplated, whether alone (that is, substantially free of other isomers), in admixture with  
10 certain stereoisomers (for example, as a racemate) or in any other mixture thereof. It is preferred that these compounds be substantially free of other stereoisomers.

          The present invention is further described by the following examples which are illustrative only, and are in  
15 no way intended to limit the scope of the present claims.

Abbreviations

The following abbreviations have the indicated meaning throughout the present specification.

5

Ac = acetyl

Bz = -C(O)-Ph (i.e., benzoyl)

DCC = dicyclohexylcarbodiimide

DMAP = dimethylaminopyridine

10 DMF = dimethylformamide

Et = ethyl

EtOAc = ethyl acetate

MOP = 1-methoxy-1-methylethyl

Ph = phenyl

15 HI = homogeneity index

PMA = phosphomolybdic acid

PPTS = pyridinium p-toluene sulfonate

TEA = triethylamine

TES = triethylsilyl

20 THF = tetrahydrofuran

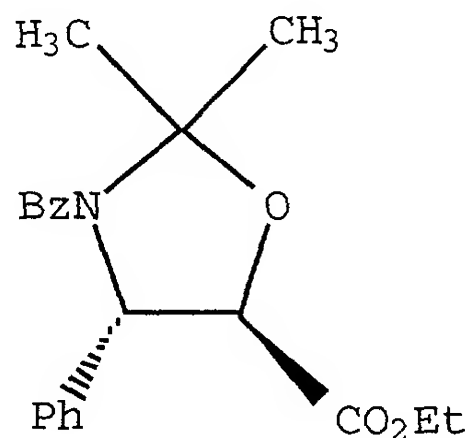
TLC = thin layer chromatography

The following Examples 1 to 4 demonstrate cyclizations forming a preferred oxazolidine ester compound of the formula I or II of the present invention.

5

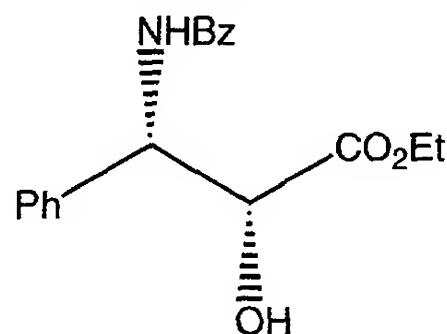
EXAMPLE 1

Preparation of (4S-trans)-3-Benzoyl-2,2-dimethyl-4-phenyl-5-oxazolidinecarboxylic acid, ethyl ester



10

$[R-(R^*, S^*)] - \beta - (\text{Benzoylamino}) - \alpha -$   
hydroxybenzenepropanoic acid, ethyl ester:



15 (225 mg, 0.7183 mmol) was suspended in methylene chloride (CH<sub>2</sub>Cl<sub>2</sub>, 3.0 ml), and DMF (2.0 ml) was added until a clear solution resulted. The mixture was cooled to 0°C, and 2-methoxypropene (1.7957 mmol) was added, followed by PPTS (approximately 5 mg, 0.016 mmol). The mixture was stirred  
20 for 4 hours, then another 2.6 eq. (1.7957 mmol) of 2-methoxypropene were added. The addition was repeated twice more at intervals of 2 hours, and the mixture was allowed to stand overnight at room temperature. The reaction was quenched with saturated NaHCO<sub>3</sub>, and the mixture was washed

with saturated  $\text{NaHCO}_3$ , dried, and the solvent removed to give the product in quantitative yield. The residue was refluxed in an excess of toluene and 2,2-dimethoxypropane and azeotroped overnight. HPLC isolation gave 73 mg of the  
5 title product (29%).

TLC (hexanes/ethyl acetate = 2:1)  $R_f$  = 0.48

m.p. = 87-88 C

$^1\text{H}$  NMR in accordance with the above structure.

10

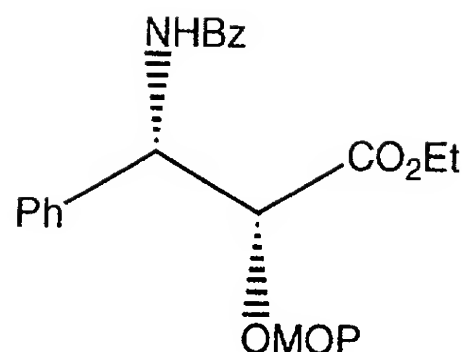
EXAMPLE 2

Alternative Preparations (A) and (B) of (4*S*-trans)-3-Benzoyl-2,2-dimethyl-4-phenyl-5-oxazolidinecarboxylic acid, ethyl ester

15

(A)  $[R-(R^*, S^*)]-\beta$ -(Benzoylamino)- $\alpha$ -hydroxybenzenepropanoic acid, ethyl ester (2.200 mg) was suspended in toluene (250 ml) and the flask equipped with a Dean-Stark trap. After heating to reflux, the compound dissolved. 40 ml of toluene were distilled off, PPTS (120  
20 mg) and 2-methoxypropene (3.5 ml) were added, and distillation was continued. Further additions of 2-methoxypropene (2 ml, and then 1 ml) and toluene (50 ml, and then another 50 ml) were made, and the distillate periodically discarded. Purification on HPLC (hexane/ethyl  
25 acetate, 3:1) gave 2.3 g (93%) of the title product in a mixture with other reaction products. (Product characteristics consistent with structure of Example 1.)

(B)  $[R-(R^*, S^*)]-\beta$ -(Benzoylamino)- $\alpha$ -(1-methoxy-1-methylethoxy)benzenepropanoic acid, ethyl ester:  
30

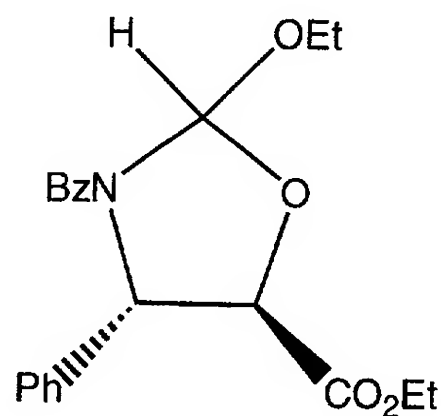


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(2.200 mg) was mixed with toluene (200 ml) and PPTS (75 mg) was added. The mixture was heated and toluene removed in a Dean-Stark trap. After 70 ml of toluene were removed, a TLC was conducted which showed a mixture of products and the hydroxyester starting material of Example 1. 2-Methoxypropene (0.5 ml) was added and the distillation continued. A second charge of 2-methoxypropene (0.5 ml) was added and the distillation continued. When the volume dropped to about 70 ml, TLC showed only the title product. It was purified by HPLC (hexanes/ethyl acetate, 5:1 to 1:1) to give 1.56 mg of the title product (75% overall yield from the starting compound) in admixture with other reaction products. (Product characteristics consistent with structure of Example 1.)

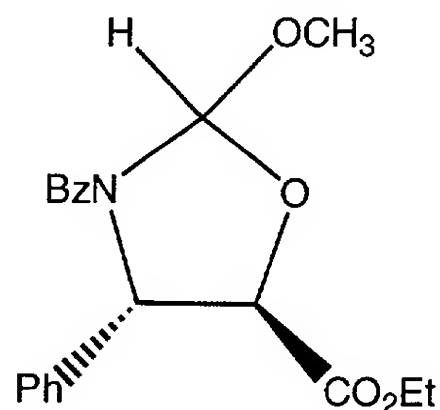
EXAMPLE 3Preparation of (4S,5R)-3-Benzoyl-2-ethoxy-4-phenyl-5-oxazolidinecarboxylic acid, ethyl ester

5



- 10 [R-(R\*, S\*)]- $\beta$ -(Benzoylamino)- $\alpha$ -hydroxybenzenepropanoic acid, ethyl ester (1.16 mmol) is suspended in benzene (10 ml), and triethoxymethane (3.44 mmol) and PPTS (72 mg) are added. Heating to reflux provides the title compound.

## EXAMPLE 4

Preparation of (4S,5R)-3-Benzoyl-2-methoxy-4-phenyl-5-oxazolidinecarboxylic acid, ethyl ester

5

(A) [R-(R\*,S\*)]- $\beta$ -(Benzoylamino)- $\alpha$ -hydroxybenzenepropanoic acid, ethyl ester (1.16 mmol) was suspended in benzene (10 ml), and trimethoxymethane (3.44 mmol) and PPTS (72 mg) were added. Heating to reflux (103°C) did not dissolve the starting compound. 2 ml of DMF were then added so that most of the starting compound dissolved, although the solution remained somewhat turbid. The flask was equipped with a Soxhlet extractor. The thimble of the extractor was filled with 4Å mol. sieves. After 1 hour, and approximately 3 to 4 cycles in the Soxhlet extractor, TLC showed consumption of the starting material, and a new major spot of the title product. It was diluted with EtOAc, washed with NaHCO<sub>3</sub> and H<sub>2</sub>O, dried and the solvent removed. NMR showed the presence of the title product and a small impurity. The product was purified on HPLC (hexane:ethyl acetate, 3:1) to give 358 mg (87%) of the title product.



(B) Preparation of the title compound was conducted on a larger scale as follows. [R-(R\*,S\*)]- $\beta$ -(Benzoylamino)- $\alpha$ -hydroxybenzenepropanoic acid, ethyl ester (3.138 g) was  
5 suspended in benzene (100 ml), and trimethoxymethane (3.190 g) and PPTS (628 mg) were added. The reaction solution was heated to reflux, 20 ml of DMF were added for dissolution of most of the starting compound, followed by heating with a Soxhlet extractor. The thimble in the extractor was filled  
10 with 4Å mol. sieves. After 1 hour, and approximately 3 to 4 cycles in the Soxhlet extractor, TLC showed consumption of the starting material, and a new major spot of the title product. It was diluted with EtOAc, washed with NaHCO<sub>3</sub> and H<sub>2</sub>O, dried and the solvent removed. NMR showed the presence  
15 of the title product and a small impurity. The product was purified on HPLC (hexane:ethyl acetate, 3:1) to give 3.138 g (97%) of the title product. The product (an oil) was a mixture of diastereomers (not separated).

Mass spec.: M+H<sup>+</sup> = 356

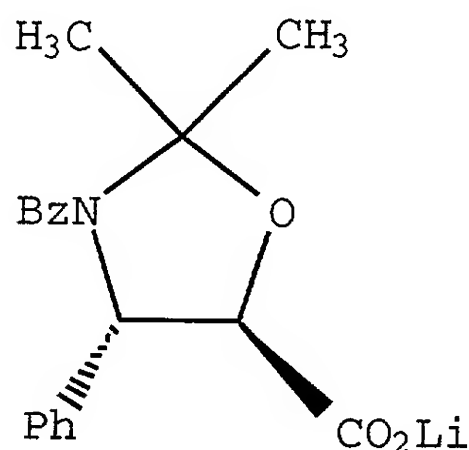
20 TLC (hexanes/ethyl acetate = 2:1) R<sub>f</sub> = 0.41

<sup>1</sup>H NMR in accordance with the above structure.

The following Examples 5 to 7 demonstrate hydrolysis of the ester group of a preferred oxazolidine ester of the  
25 formula I or II to form the corresponding carboxylic acid, or salt thereof, of the formula III or VII.

EXAMPLE 5Preparation of (4S-trans)-3-Benzoyl-2,2-dimethyl-4-phenyl-5-oxazolidinecarboxylic acid, lithium salt

5

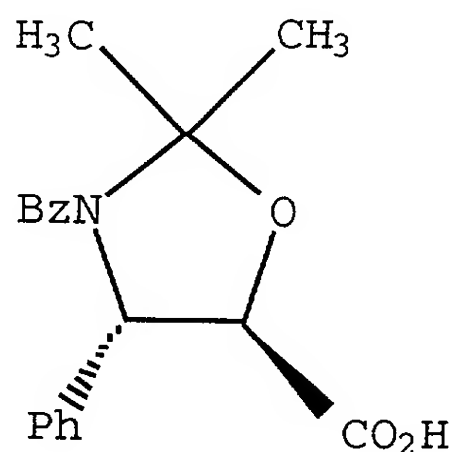


10 (4S-trans)-3-Benzoyl-2,2-dimethyl-4-phenyl-5-oxazolidinecarboxylic acid, ethyl ester (73 mg) was dissolved in THF (0.5 ml) at room temperature and LiOH (0.217 ml, 1M in H<sub>2</sub>O) was added dropwise. Initially, a bi-phasic mixture was observed, but after the addition of the last quantity of LiOH and stirring for 5 minutes the solution became homogeneous. After further stirring for 1/2

15 hour, the solvents were removed *in vacuo*. The residue was azeotroped with toluene/methanol and dried at 55°C overnight under high vacuum. The title lithium salt was obtained (no further purification).

EXAMPLE 6Preparation of (4S-trans)-3-Benzoyl-2,2-dimethyl-4-phenyl-5-oxazolidinecarboxylic acid

5



10 (4S-trans)-3-Benzoyl-2,2-dimethyl-4-phenyl-5-oxazolidinecarboxylic acid, ethyl ester (1.56 g) was dissolved in THF (10 ml) at room temperature and LiOH (4.63 ml, 1M in H<sub>2</sub>O) was added dropwise. Initially, a bi-phasic mixture was observed, but after the addition of the last quantity of LiOH and stirring for 5 minutes the solution became homogeneous. After further stirring for 1/2 hour,

15 the reaction mixture was quenched with aqueous 1N HCl (4.63 ml), and diluted with EtOAc and saturated NaCl. The H<sub>2</sub>O layer (pH = 3) was twice extracted with EtOAc, and the combined organic phase dried with MgSO<sub>4</sub>. The solvent was removed in vacuo to give 1.39 g of the title product acid

20 (97%) which was homogeneous by TLC and <sup>1</sup>H NMR.

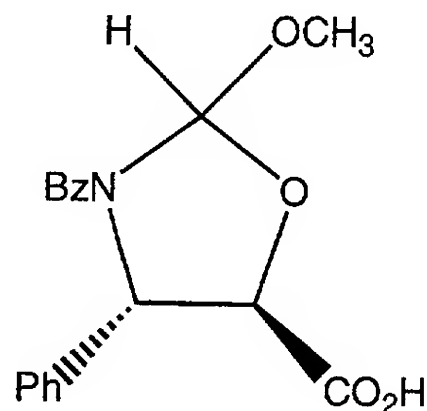
TLC (ethyl acetate/acetone/methanol/water = 7:1:1:1)

R<sub>f</sub> = 0.40

m.p. = 173-176°C

<sup>1</sup>H NMR in accordance with the above structure.

25

EXAMPLE 7Preparation of (4S, 5 $\beta$ )-3-Benzoyl-2-methoxy-4-phenyl-5-oxazolidinecarboxylic acid

5

A procedure analogous to that of Example 6 was employed, substituting the title product of Example 4 (177 mg) in place of the title product of Example 1 and employing the following amounts of the remaining reagents: 0.524 ml 1N LiOH, 2.0 ml THF and 0.524 1N HCl. 161 mg of the crude title product (99%) was obtained. The same procedure was carried out at a larger scale (using 3,580 mg of the title product of Example 4, 10.38 ml of 1N LiOH, 40 ml of THF, and 10.38 ml of 1N HCl) to yield 3.23 g of the crude title product (98%) (minor impurity present). The product was a mixture of diastereomers (not separated).

TLC (ethyl acetate/acetone/methanol/water = 7:1:1:1)

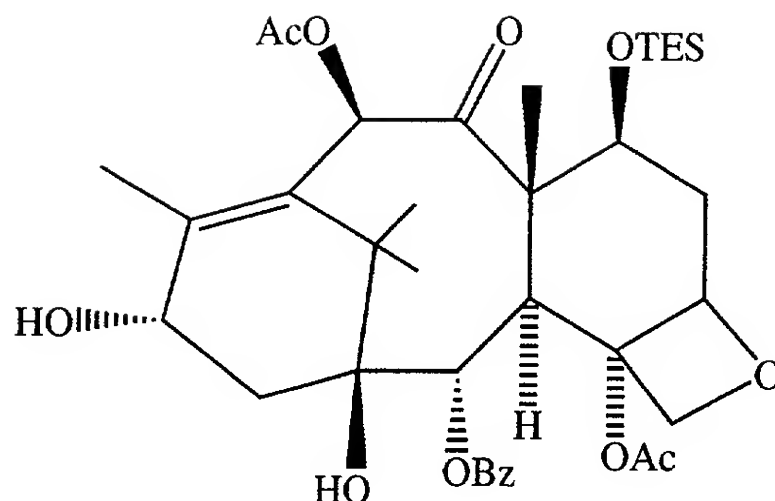
20  $R_f = 0.35$

m.p. (mixture) = 160-162°C

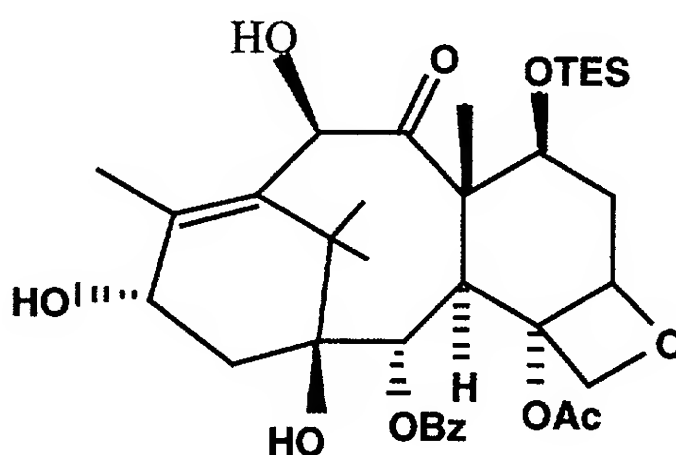
$^1\text{H}$  NMR in accordance with the above structure.

25 The following Example 8 demonstrates the preparation of a preferred starting C-13 hydroxyl-bearing taxane material of the formula IV.

EXAMPLE 8Preparation of 7-Triethylsilylbaccatin III



- (i) [2aR-(2a $\alpha$ , 4 $\beta$ , 6 $\beta$ , 9 $\alpha$ , 11 $\beta$ , 12 $\alpha$ , 12a $\alpha$ , 12b $\alpha$ )]-  
Benzoic acid, 12b-acetyloxy-2a,3,4,4a,5,-  
6,9,10,11,12,12a,12b-dodecahydro-6,9,11-  
trihydroxy-4a,8,13,13-tetramethyl-5-oxo-  
4-[(triethylsilyl)oxy]-7,11-methano-1H-  
cyclodeca[3,4]benz[1,2-b]oxet-12-yl ester  
(7-O-TES-10-Desacetyl baccatin III)



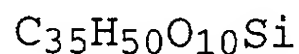
10-Desacetyl baccatin III (27.4 g, 50.3 mmol) (amount not corrected for impurities measured (twice) as: H<sub>2</sub>O: 1.0% (1.57%), CH<sub>3</sub>OH: 1.49% (1.6%), ethyl acetate: 0.1% (0.09%), hexane (0.03%)) and 4-dimethylaminopyridine (2.62 g, 21.4 mmol) (wt. % H<sub>2</sub>O (K.F.) = 0.09) were added to a flame-dried, argon purged 1 L 3-necked flask (equipped with a mechanical stirrer and a digital thermometer) and were dissolved in dry dimethylformamide (122 ml) (wt. % H<sub>2</sub>O (K.F.) = <0.01). CH<sub>2</sub>Cl<sub>2</sub> (256 ml) (wt. % H<sub>2</sub>O (K.F.) = <0.01) was added and the

resulting homogeneous solution was cooled to  $-50^{\circ}\text{C}$ . (The temperature of the reaction solution rose from  $23^{\circ}\text{C}$  to  $25^{\circ}\text{C}$  during the addition of  $\text{CH}_2\text{Cl}_2$ .) Triethylamine ( $\text{NEt}_3$ , 16 ml, 120 mmol) (wt. %  $\text{H}_2\text{O}$  (K.F.) = 0.08) was added dropwise over 5 3 minutes and the resulting solution was stirred at  $-50^{\circ}\text{C}$  for 5 minutes before the dropwise addition of neat triethylsilyl chloride ( $\text{Et}_3\text{SiCl}$ , 18.6 ml, 111 mmol). The addition of  $\text{Et}_3\text{SiCl}$  was conducted over a period of 10 minutes and the temperature of the reaction did not rise 10 above  $-50^{\circ}\text{C}$ . The reaction became very cloudy during the addition of  $\text{Et}_3\text{SiCl}$ . The resulting mixture was stirred at  $\sim -50^{\circ}\text{C}$  for 1 hour and was then allowed to stand (without stirring) in a  $-48^{\circ}\text{C}$  freezer for 22 hours. (A separate experiment showed that stirring the reaction at  $-48^{\circ}\text{C}$  for 8 15 hours resulted in  $\sim 60\%$  conversion.) The mixture was then removed from the freezer and warmed to  $\sim -10^{\circ}\text{C}$ . (TLC analysis of the mixture (solvent: ethyl acetate, stain: phosphomolybdic acid/ethanol) revealed the absence of starting material and showed a single spot for the product 20 ( $R_f = 0.60$ )). The cold mixture was combined with EtOAc (1L) and washed with  $\text{H}_2\text{O}$  (890 ml). The resulting aqueous layer was separated and extracted with EtOAc (250 ml). The combined organic layers were washed with 5.7% aqueous  $\text{NaH}_2\text{PO}_4$  (2 x 250 ml) (measured pH of 5.7% aqueous  $\text{NaH}_2\text{PO}_4 =$  25  $4.30 \pm 0.05$ ; measured pH of the combined  $\text{NaH}_2\text{PO}_4$  washings =  $5.75 \pm 0.05$ ), half-saturated aqueous NaCl (250 ml), saturated aqueous NaCl (250 ml), dried over  $\text{Na}_2\text{SO}_4$ , filtered and concentrated on a rotovap. (All concentrations on the rotovap were conducted with a water bath temperature of 30  $35^{\circ}\text{C}$ .) The resulting semi-solid was further dried by exposure to high vacuum ( $\sim 1$  mm Hg for 20 minutes) to give 41.5 g of a white solid. The crude product was then dissolved in  $\text{CH}_2\text{Cl}_2$  (400 ml) (heating in a  $35^{\circ}\text{C}$  water bath

was required to dissolve the solid) and the volume of the resulting solution was reduced to ~150 ml on a rotovap. Crystallization started immediately and the mixture was allowed to stand at room temperature for 1 hour. Hexanes (100 ml) were added and the mixture was gently swirled. The mixture was allowed to stand in a 4°C cold room for 16.5 hours. The solid was filtered, washed with 1:9 CH<sub>2</sub>Cl<sub>2</sub>/hexanes (3 x 250 ml) on a suction filter, and dried under high vacuum (~0.2 mm Hg for 42 hours) to give 26.1 g (79%) of the title product as a white powder. The mother liquor was concentrated on a rotovap and the residue was crystallized from CH<sub>2</sub>Cl<sub>2</sub> to give 4.5 g (14%) of the title product as white crystals. Recrystallization was conducted in the same manner as with the first crop of product: the solid was dissolved in CH<sub>2</sub>Cl<sub>2</sub> (100 ml) without heating and the volume of the resulting solution was reduced to ~7 ml on a rotovap. Crystallization began within 5 minutes. The mixture was allowed to stand at room temperature for 1 hour, then in a 4°C cold room for 42 hours. The crystals were filtered, washed with 1:9 CH<sub>2</sub>Cl<sub>2</sub>/hexanes (3 x 50 ml) on a suction filter, and dried under high vacuum (~0.2 mm Hg for 18 hours.). The <sup>1</sup>H NMR of this crop was identical to the <sup>1</sup>H NMR of the first crop of product.

The combined yield for the two crops was 93% (uncorrected).

#### Elemental Analysis (%)



	Calcd.	Found
C	63.80	63.43
H	7.65	7.66
KF(H <sub>2</sub> O)	0.00	0.00

mp: 239 - 242°C (decomp.)

$[\alpha]^{22}_{\text{D}}$ : -53.6° (c 1.0, CHCl<sub>3</sub>)

TLC:  $R_f$  = 0.60 (silica gel, EtOAc); visualized by phosphomolybdic acid/ethanol.

An alternative procedure was employed as follows:

In a flame-dried 250 ml 3-necked flask equipped with an argon inlet was placed 10-des-acetylbaccatin III (5.44 g, 10 mmol, having a water content of 1.56 wt. % and a methanol content of 1.6 wt %), 4-dimethylaminopyridine (0.49 g, 4 mmol) and N,N-dimethylformamide (24 ml, dried over 4Å molecular sieve). The mixture was stirred at room temperature until homogeneous. Dichloromethane (50 ml, HPLC grade, used without purification) was added and the temperature was lowered to -50°C. Triethylamine (2.9 ml, 21 mmol) was added dropwise over a 5 minute period, followed by triethylsilylchloride (3.4 ml, 20 mmol) over a 10 minute period. The mixture was allowed to stand at -48°C for a period of 21 hours, diluted with 200 ml of ethyl acetate and 175 ml of water. (The reaction was monitored by TLC using EtOAc as eluent:  $R_f$  for the starting material = 0.56,  $R_f$  for the product = 0.83; UV and PMA visualization.) The aqueous layer was separated and extracted with ethyl acetate (50 ml x 1). The organic layers were combined and washed with 5% aqueous potassium phosphate mono basic (50 ml x 2) (pH of 5%  $\text{KH}_2\text{PO}_4$  in  $\text{H}_2\text{O}$  was 4.3), half-saturated sodium chloride (50 ml x 1), brine (50 ml x 1), dried over sodium sulfate and concentrated *in vacuo* to give crude title product as a solid (7.45 g). The crude material was dissolved in 75 ml of hot dichloromethane and the total volume was reduced to 30 ml by heating to begin crystallization. It was set aside at room temperature for 2 hours and 4°C for 16 hours. The crystals were filtered on a buchner funnel, washed with cold 10% dichloromethane in hexane (25 ml) and dried *in vacuo* to afford 5.38 g of title product. The mother liquors and washings were concentrated *in vacuo* and the solid residue



was crystallized by dissolving in 8 ml of dichloromethane. Following the above crystallization procedure, 0.72 g of the product was obtained as a second crop. The combined yield of the title product 7-TES-10-desacetylbaccatin III, as a white solid (m.p. 238-240°C), was 6.10 g (93%).

Elemental Analysis (%)

$C_{35}H_{50}O_{10}Si$

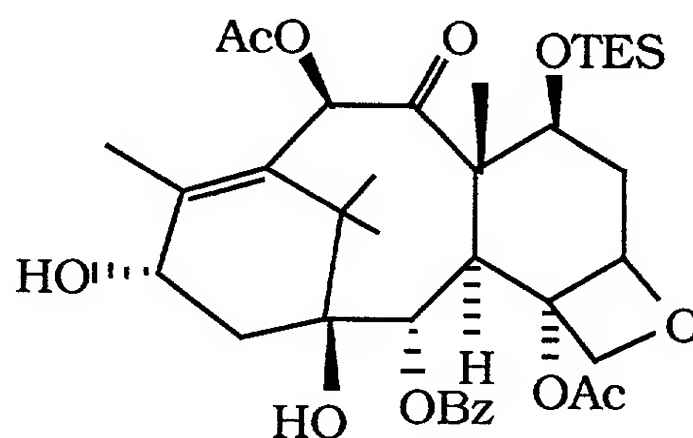
	Calcd.	Found
C	63.80	63.76
H	7.65	7.66

mp: 239 - 242°C

$[\alpha]_D$ : -53.7 (c 1.0,  $CHCl_3$ )

TLC:  $R_f$  = 0.53 (silica gel, 50% EtOAc in hexane); UV and PMA visualization. HI = 98.9%

(ii) [2aR-(2a $\alpha$ , 4 $\beta$ , 4a $\beta$ , 6 $\beta$ , 9 $\alpha$ , 11 $\beta$ , 12 $\alpha$ , 12a $\alpha$ , 12b $\alpha$ )]-  
6, 12b-Bis(acetyloxy)-12-(benzoyloxy)-2a, 3, -  
4, 4a, 5, 6, 9, 10, 11, 12, 12a, 12b-dodecahydro-  
9, 11-dihydroxy-4a, 8, 13, 13-tetramethyl-  
4-[(triethylsilyl)oxy]-7, 11-methano-1H-  
cyclodeca[3, 4]benz[1, 2-b]oxet-5-one  
(7-O-TES-baccatin III)



7-O-TES-10-desacetylbaccatin III prepared in step (i) above (21.4 g, 32.4 mmol) was added to a flame-dried, argon purged 1L 3-necked flask (equipped with a mechanical stirrer

and a digital thermometer) and dissolved in THF (350 ml, freshly distilled from sodium/benzophenone). The resulting solution was cooled to  $-70^{\circ}\text{C}$ . A solution of n-butyllithium (n-BuLi, 14.6 ml of a 2.56 M solution in hexanes, 37.3 mmol, 5 titrated in triplicate with diphenylacetic acid in THF at  $0^{\circ}\text{C}$ ) was added dropwise over a period of 23 minutes. The temperature of the reaction did not rise above  $-68^{\circ}\text{C}$  during the addition. Solids were formed upon the addition of n-BuLi and did not appear to dissolve at 10  $-70^{\circ}\text{C}$ . The resulting mixture was stirred at  $-70^{\circ}\text{C}$  for 20 minutes and was then warmed to  $-48^{\circ}\text{C}$ . (A clear homogeneous solution was obtained upon warming to  $-48^{\circ}\text{C}$ .) After stirring at  $-48^{\circ}\text{C}$  for 1/2 hour, acetic anhydride (4.6 ml, 49 mmol, distilled (137 -  $138^{\circ}\text{C}$ , 1 atm) under an 15 atmosphere of argon before use) was added dropwise over 7 minutes. The temperature of the reaction did not rise above  $-45^{\circ}\text{C}$  during the addition. The resulting solution was stirred at  $-48^{\circ}\text{C}$  for 20 minutes and then at  $0^{\circ}\text{C}$  for 1 hour. The solution was diluted with ethyl acetate (350 ml), washed 20 with saturated aqueous  $\text{NH}_4\text{Cl}$  (250 ml), and the layers were separated. The aqueous layer was extracted with ethyl acetate (200 ml). The combined organic layers were washed with saturated aqueous NaCl, dried over  $\text{Na}_2\text{SO}_4$ , filtered, and concentrated on a rotovap. (All concentrations on the 25 rotovap were conducted with a water bath temperature of  $35^{\circ}\text{C}$ .) Exposure of the semi-solid to high vacuum ( $\sim 1.5$  mm Hg for 1/2 hour) gave 24.7 g of a white solid. The crude product was dissolved in  $\text{CH}_2\text{Cl}_2$  (300 ml) and the volume of the resulting solution was reduced to  $\sim 70$  ml on a rotovap. 30 Crystallization began within one minute. The mixture was allowed to stand at room temperature for 45 minutes, and then in a  $4^{\circ}\text{C}$  cold room for 18 hours. The crystals were filtered, washed with 1:9  $\text{CH}_2\text{Cl}_2$ /hexanes (3 x 100 ml) on a suction filter, and dried under high vacuum ( $\sim 0.2$  mm Hg for

19 hours) to give 20.9 g (92.0%) of the title product as fine white needles. The mother liquor was concentrated on a rotovap and the residue was crystallized from CH<sub>2</sub>Cl<sub>2</sub>/hexanes to give 0.82 g (3.6%) of the title product as small white crystals. Crystallization was conducted as follows: The residue was dissolved in CH<sub>2</sub>Cl<sub>2</sub> (10 ml) and the volume of the resulting solution was reduced to ~5 ml on the rotovap. After standing at room temperature for 1/2 hour, no crystals had formed. Hexanes (5 ml) were added in 1 ml portions and the solution was swirled. A few crystals were present by this time. The mixture was allowed to stand at room temperature for 1/2 hour (more crystals formed) and then in a 4°C cold room for 18 hours. The crystals were filtered, washed with 1:9 CH<sub>2</sub>Cl<sub>2</sub>/hexanes on a suction filter, and dried under high vacuum (~0.15 mm Hg for 21 hours).

The combined yield for the two crops was 95.6%.

mp: 218 - 219°C (decomp.)

$[\alpha]^{22}_D$ : -78.4° (c 1.0, CHCl<sub>3</sub>)

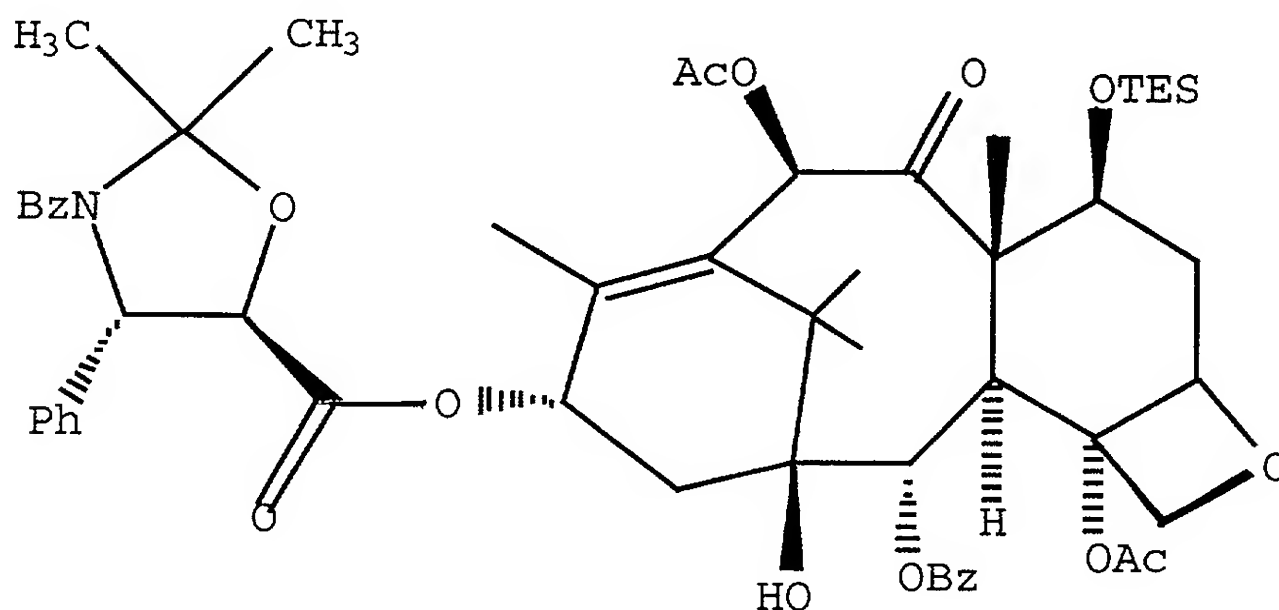
- 5 TLC:  $R_f$  = 0.37 (silica gel, 1:9 acetone/CH<sub>2</sub>Cl<sub>2</sub>); visualized by phosphomolybdic acid/ethanol.

10 The following Examples 9 to 11 demonstrate the coupling of a preferred oxazolidine carboxylic acid of the formula III or VII with a C-13 hydroxyl-bearing taxane of the formula IV.

#### EXAMPLE 9

##### Preparation of [2aR-

- 15 (2a $\alpha$ , 4 $\beta$ , 4a $\beta$ , 6 $\beta$ , 9 $\alpha$ (4S\*, 5R\*), 11 $\alpha$ , 12 $\alpha$ , 12a $\alpha$ , 12b $\alpha$ )]-3-Benzoyl-2,2-dimethyl-4-phenyl-5-oxazolidinecarboxylic acid 6,12b-bis(acetyloxy)-12-(benzoyloxy)-  
2a, 3, 4, 4a, 5, 6, 9, 10, 11, 12, 12a, 12b-dodecahydro-11-hydroxy-4a, 8, 13, 13-tetramethyl-5-oxo-4-[(triethylsilyl)oxy]-7, 11-  
 20 methano-1H-cyclodeca[3,4]benz[1,2-b]oxet-9-yl ester



- 25 7-Triethylsilylbaccatin III (156 mg), the title product of Example 6 (94 mg), toluene (0.6 ml), DCC (69 mg) and DMAP (27 mg) were mixed together and the resulting

mixture was heated at 80°C for 3 hours. TLC at that time showed complete consumption of the 7-triethylsilylbaccatin III starting material and the appearance of a new spot. The reaction mixture was diluted with CH<sub>2</sub>Cl<sub>2</sub> (20 ml), saturated aqueous NaHCO<sub>3</sub> (10 ml) was added, the H<sub>2</sub>O layer was extracted with CH<sub>2</sub>Cl<sub>2</sub> (2 x 10 ml) and the combined organic layers were dried over anhydrous MgSO<sub>4</sub>. Upon concentration *in vacuo* some precipitate was formed which was removed by filtration. The compound was purified by preparative HPLC (hexane:ethyl acetate, 2:1) to give 214 mg (96%) of the title product.

Mass spec.: M+H<sup>+</sup> = 1,008

TLC (hexanes/ethyl acetate = 1:1) R<sub>f</sub> = 0.56

m.p. = 164-165°C

<sup>1</sup>H NMR in accordance with the above structure.

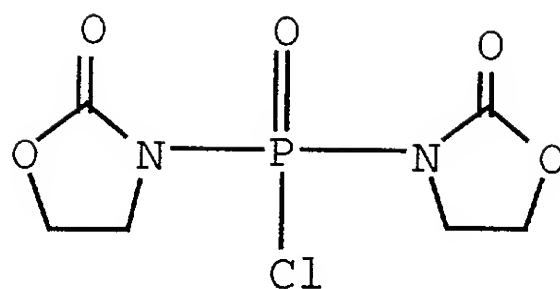
The above procedure was repeated on a larger scale employing 7-triethylsilylbaccatin III (475 mg), the title product of Example 6 (287 mg), toluene (1.8 ml), DCC (210 mg) and DMAP (50 mg). HPLC chromatography yielded 666 mg (98%) of the title product.

#### EXAMPLE 10

##### Alternative Preparation of [2aR-

(2a $\alpha$ , 4 $\beta$ , 4a $\beta$ , 6 $\beta$ , 9 $\alpha$ (4S\*, 5R\*), 11 $\alpha$ , 12 $\alpha$ , 12a $\alpha$ , 12b $\alpha$ )]-3-Benzoyl-2,2-dimethyl-4-phenyl-5-oxazolidinecarboxylic acid 6,12b-bis(acetyloxy)-12-(benzoyloxy)-2a,3,4,4a,5,6,9,10,11,12,12a,12b-dodecahydro-11-hydroxy-4a,8,13,13-tetramethyl-5-oxo-4-[(triethylsilyl)oxy]-7,11-methano-1H-cyclodeca[3,4]benz[1,2-b]oxet-9-yl ester

A suspension of the title product of Example 6 (103 mg), bis(2-oxo-3-oxazolidinyl)phosphinic chloride (65 mg) having the structure:

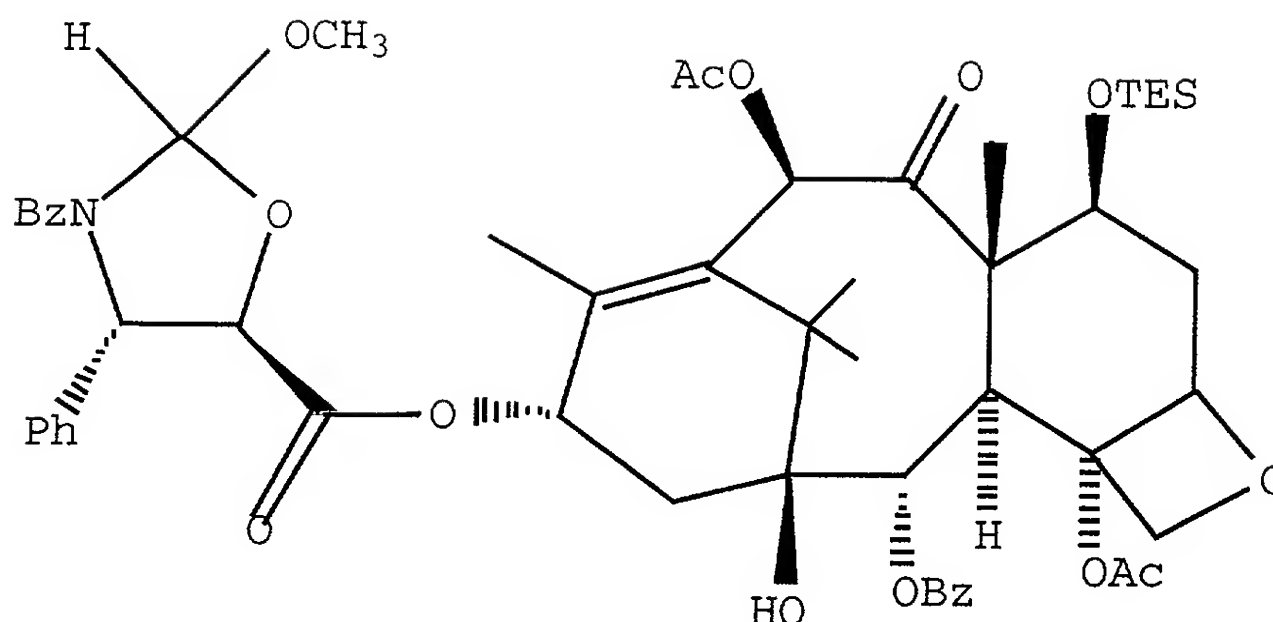


and 7-triethylsilylbaccatin III (170 mg) in CH<sub>2</sub>Cl<sub>2</sub> (0.5 ml)  
 5 and TEA (0.068 ml) was stirred at room temperature for 3  
 hours. After 1/2 hour the suspension became a somewhat  
 cloudy solution. No reaction was observed by TLC. The  
 mixture was then heated under reflux for 1 hour (no  
 reaction). At that time, DMAP was added and heating  
 10 continued for 1 hour resulting in product formation. The  
 mixture was diluted with ethyl acetate, washed with  
 saturated aqueous NaHCO<sub>3</sub>, pH 3 phosphate buffer, saturated  
 aqueous NaCl, dried and evaporated to give 232 mg (95%) of  
 the crude product. <sup>1</sup>H NMR showed the desired title product  
 15 and about 2 to 5% starting material. (Product  
 characteristics consistent with structure of Example 9.)

#### EXAMPLE 11

##### Preparation of [2aR-

20 (2a $\alpha$ , 4 $\beta$ , 4a $\beta$ , 6 $\beta$ , 9 $\alpha$ (4S\*, 5R\*), 11 $\alpha$ , 12 $\alpha$ , 12a $\alpha$ , 12b $\alpha$ )]-3-Benzoyl-2-  
methoxy-4-phenyl-5-oxazolidinecarboxylic acid 6,12b-  
bis(acetyloxy)-12-(benzoyloxy)-  
2a, 3, 4, 4a, 5, 6, 9, 10, 11, 12, 12a, 12b-dodecahydro-11-hydroxy-  
4a, 8, 13, 13-tetramethyl-5-oxo-4-[(triethylsilyl)oxy]-7,11-  
 25 methano-1H-cyclodeca[3,4]benz[1,2-b]oxet-9-yl ester



7-Triethylsilylbaccatin III (255 mg), the title product of Example 7 (155 mg), toluene (1.0 ml), DCC (113 mg) and DMAP (27 mg) were mixed together and the resulting mixture was heated to reflux (about 80°C) for 1 hour. At that time, the reaction was not complete and a second charge of DCC (56.5 mg) and DMAP (13.5 mg) were added and the mixture was refluxed for another 2 hours. Small amounts of starting material still remained. After work-up (dilution with EtOAc, washing with saturated aqueous NaHCO<sub>3</sub>, and drying with anhydrous MgSO<sub>4</sub>), the product was purified on preparative HPLC. The main fractions gave 300 mg (82%) of the title product (and a small amount of impurity).

On a larger scale, 7-triethylsilylbaccatin III (1.022 g), the title product of Example 7 (620 mg), DCC (451 mg) and DMAP (107 mg) were mixed together in a dry flask and suspended in toluene (3.5 ml). The mixture was heated at 80°C for 1 hour, then another 0.5 eq. of the title product of Example 7 was added, followed by a second charge of DMAP (107 mg) and DCC (451 mg). Starting material still remained after heating for 1 hour. The reaction mixture was heated overnight and worked-up as described above. Purification on HPLC (hexane:ethyl acetate, 9:1 → 1:1) gave as the first fraction 75 mg of an impurity, then the title product (928

mg, 65%). 213 mg of starting material (21%) remained. The product was a mixture of diastereomers (not separated).

TLC (hexanes/ethyl acetate = 1:1)  $R_f$  = 0.51

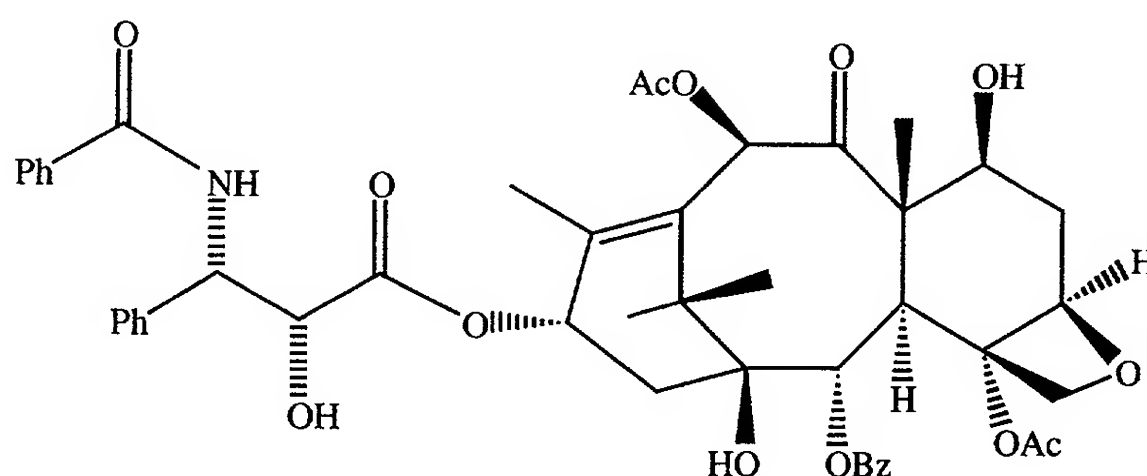
m.p. (mixture) = 152-155°C

5  $^1\text{H}$  NMR in accordance with the above structure.

The following Examples 12 to 13 demonstrate ring opening of preferred coupled products of the formula V or VIII to yield a C-13 acyloxy sidechain-bearing taxane of the  
10 formula VI.

#### EXAMPLE 12

##### Preparation of Paclitaxel



15

The title product of Example 11 (106 mg) was dissolved in THF (1.5 ml) and cooled to 0°C. 10% aqueous HCl (0.5 ml) and acetic acid (0.5 ml) were added. The  
20 reaction mixture was stirred at 0°C for 5 hours. It was then stirred for 2 hours at room temperature, followed by storage overnight at 4°C. As the reaction was still not complete, the mixture was then stirred at room temperature for 5 hours after which time no starting material was  
25 detectable by TLC. After work-up (dilution with EtOAc, washing with saturated  $\text{NaHCO}_3$  and brine, and drying with  $\text{MgSO}_4$ ), it was purified by preparative HPLC (hexane:ethyl



actetate, 5:1  $\rightarrow$  1:2) to give 70 mg (78%) of the title product. (Product characteristics consistent with those of an authentic sample of the natural product.)

5

EXAMPLE 13Preparation of Paclitaxel

10 The title product of Example 9 (0.084 mmol) was dissolved in acetone (1.0 ml), Pd(CH<sub>3</sub>CN)<sub>2</sub>Cl<sub>2</sub> (0.5 mg) was added (from tip of spatula), and the mixture was stirred at room temperature. After 2 hours, deprotection of the 7-triethylsilyl group was observed to a small extent (additional polar spots on TLC were observed). Further stirring gave additional deprotection of the 7-triethylsilyl group, although some starting material still remained. 15 Another portion of Pd(CH<sub>3</sub>CN)<sub>2</sub>Cl<sub>2</sub> (0.5 mg) was added and stirring was continued overnight. At this time, paclitaxel, the starting acetonide taxane and an analog of the starting acetonide taxane in which the 7-position triethylsilyl group had been deprotected to form a hydroxyl group were observed by TLC. A third portion of Pd(CH<sub>3</sub>CN)<sub>2</sub>Cl<sub>2</sub> (0.5 mg) was added 20 and stirring was continued for 8 hours (deprotecting the 7-position triethylsilyl group; at this time, a small amount of starting material remained with amounts of impurities more polar than paclitaxel). The reaction mixture was 25 quenched with saturated NaHCO<sub>3</sub>, worked up by diluting with ethyl acetate, washing with H<sub>2</sub>O followed by saturated aqueous NaCl, and drying with anhydrous MgSO<sub>4</sub>. The solvents were removed *in vacuo* and the residue was purified by HPLC 30 (hexane:ethyl acetate, 2:1  $\rightarrow$  1:2) to yield 30 mg (42%) of the title product (paclitaxel). (Product characteristics consistent with those of an authentic sample of the natural product.)